EARTHQUAKE LOSS ESTIMATION METHODOLOGY

HAZUS®99

TECHNICAL MANUAL

Developed by:

Federal Emergency Management Agency
Washington, D.C.

Through a cooperative agreement with:

National Institute of Building Sciences
Washington, D.C.

Preface

Earthquakes pose a threat to life and property in 45 states and territories. As the United States has become more urbanized, more frequent smaller earthquakes in the 6.5 to 7.5 Magnitude range now have the potential of causing damage equal to or exceeding the estimated $40 billion from the 1994 Northridge earthquake. Earthquakes in urban areas, such as Kobe, Japan and Izmit, Turkey, are grim reminders of the kind of damage that may result from larger earthquakes, like the San Francisco event of 1906 and eastern events that occurred in New Madrid in 1811-12.

The Federal Emergency Management Agency is committed to mitigation as a means of reducing damages and the social and economic impacts from earthquakes. FEMA, under a Cooperative Agreement with the National Institute of Building Sciences, has developed HAZUS®99 (HAZUS® stands for "Hazards U.S."), the second edition of the standard, nationally-applicable methodology for assessing earthquake risk. Significant enhancements have been added to HAZUS®99, particularly, a disaster response application to facilitate the use of HAZUS® in the immediate post-disaster environment. HAZUS®99 and the preceding edition of the earthquake loss estimation methodology, HAZUS®97, represent the dedicated efforts of more than 130 nationally-recognized earthquake and software professionals.

HAZUS is an important component of FEMA's *Project Impact*, a national movement to create safe and disaster-resistant communities. FEMA is making HAZUS® available to all states and communities, including the almost 200 now participating in *Project Impact*, and the private sector. Communities find HAZUS® to be a valuable tool in promoting a broader understanding of potential earthquake losses and in helping to build a community consensus for disaster loss prevention and mitigation.

Since the first release of HAZUS®, FEMA has been expanding the capability of HAZUS® by initiating loss estimation models for flood and hurricane hazards. Preview versions of these flood and hurricane models are being readied for release in 2002.

I am pleased to disseminate this manual to state and local users.

Michael J. Armstrong
Associate Director for Mitigation
Federal Emergency Management Agency

Foreword

The work that provided the basis for this publication was supported by funding from the Federal Emergency Management Agency (FEMA) under a cooperative agreement with the National Institute of Building Sciences. The substance and findings of that work are dedicated to the public. NIBS is solely responsible for the accuracy of the statements and interpretations contained in this publication. Such interpretations do not necessarily reflect the views of the Federal Government.

The National Institute of Building Sciences (NIBS) is a non-governmental, non-profit organization, authorized by Congress to encourage a more rational building regulatory environment, to accelerate the introduction of existing and new technology into the building process and to disseminate technical information.

Individual copies or bulk rate orders of this report are available through the National Institute of Building Sciences. For information contact:

Philip Schneider
National Institute of Building Sciences
1201 L Street, N.W.
Washington, D.C. 20005
Fax: 202-289-1092
E-mail: pschneider@nibs.org
Website: www.nibs.org

Claire Drury
FEMA
500 C Street, SW
Washington DC, 20472
Fax: 202-646-2577
E-mail: claire.drury@fema.gov
Website: www.fema.org

MESSAGE TO USERS

HAZUS is designed to produce loss estimates for use by state, regional and local governments in planning for earthquake loss mitigation, emergency preparedness and response and recovery. The methodology deals with nearly all aspects of the built environment, and with a wide range of different types of losses. The methodology has been tested against the experience from several past earthquakes and against the judgment of experts. Subject to several limitations noted below, HAZUS has been judged capable of producing results that are credible for the intended purposes.

Uncertainties are inherent is any such loss estimation methodology. They arise in part from incomplete scientific knowledge concerning earthquakes and their effect upon buildings and facilities, and in part from the approximations and simplifications necessary for comprehensive analyses. The possible range of uncertainty, possibly a factor or two or more, is best evaluated by conducting multiple analyses, varying certain of the input parameters to which losses are most sensitive. This *User's Manual* gives guidance concerning the planning of such sensitivity studies.

Users should be aware of the following specific limitations:

> HAZUS is most accurate when applied to a class of buildings or facilities, and least accurate if applied to a particular building or facility.
>
> Accuracy of losses associated with lifelines may be less than for losses associated with the general building stock.
>
> Based on several initial abbreviated tests, the losses from small magnitude (less than M 6.0) earthquakes appear to be overestimated.
>
> Uncertainty related to the characteristics of ground motion in the Eastern U.S. is high. Conservative treatment of this uncertainty may lead to overestimation of losses in this area, both for scenario events and when using probabilistic ground motion.
>
> Pilot and calibration studies have as yet not provided an adequate test concerning the possible extent and effects of landslides and the performance of water systems.
>
> The indirect economic loss module is new and experimental. While output from pilot studies has generally been credible, this module requires further testing.

HAZUS should be regarded as a work in progress. Additional improvements and increased confidence will come with further experience in using HAZUS. To assist us in further improving HAZUS, users are invited to submit comments on methodological and software issues by letter, fax or e-mail to:

Philip Schneider
National Institute of Building Sciences
1201 L Street, N.W.
Washington, D.C. 20005
Fax: 202-289-1092
E-mail: pschneider@nibs.org

Claire Drury
Federal Emergency Management Agecy
500 C Street, SW
Washington DC, 20472
Fax: 202-646-2577
E-mail: claire.drury@fema.gov

ACKNOWLEDGMENTS

Earthquake Committee

Chairman, Robert V. Whitman, Massachusetts Institute of Technology, Cambridge, Massachusetts
Roger Borcherdt, U.S. Geological Survey, Menlo Park, California
David Brookshire, University of New Mexico, Albuquerque, New Mexico
Richard Eisner, California Office of Emergency Services, Oakland California
William Holmes, Rutherford & Chekene, San Francisco, California
Robert Olson, Robert Olson & Associates, Inc., Sacramento, California
Michael O'Rourke, Rensselaer Polytechnic Institute, Troy , New York
Henry J. Lagorio, University of California at Berkeley, Berkeley, California
Robert Reitherman, California Universities for Research in Earthquake Engineering, Richmond, California

Transportation Lifeline Subcommittee

Chairman, Michael O'Rourke, Rensselaer Polytechnic Institute, Troy, New York
Robert V. Whitman, Massachusetts Institute of Technology, Cambridge, Massachusetts
David Brookshire, University of New Mexico, Albuquerque, New Mexico
Ian Friedland, MCEER, SUNY @ Buffalo, Buffalo, NY
John Mander, SUNY @ Buffalo, Buffalo, NY

Utility Lifeline Subcommittee

Chairman, Michael O'Rourke, Rensselaer Polytechnic Institute, Troy , New York
William Holmes, Rutherford & Chekene, San Francisco, California
Thomas O'Rourke, Cornell University, Ithaca, New York
William Savage, Pacific Gas & Electric Co., San Francisco, California
Robert Reitherman, California Universities for Research in Earthquake Engineering, Richmond, California

Building Damage Subcommittee

Chairman, Robert V. Whitman, Massachusetts Institute of Technology, Cambridge, Massachusetts
William Holmes, Rutherford & Chekene, San Francisco, California
Robert Olson, Robert Olson & Associates, Inc., Sacramento, California
Scott Lawson, Risk Management Solutions, Menlo Park, California
Robert Reitherman, California Universities for Research in Earthquake Engineering, Richmond, California

Casualty Subcommittee

Chairman, Robert Reitherman, California Universities for Research in Earthquake Engineering, Richmond, California
William Holmes, Rutherford & Chekene, San Francisco, California
Robert Olson, Robert Olson & Associates, Inc., Sacramento, California
Richard Eisner, California Office of Emergency Services, Oakland California
Henry J. Lagorio, University of California at Berkeley, Berkeley, California

Project Oversight Committee

Chairman, Henry J. Lagorio,, University of California at Berkeley, Berkeley, California
Arrietta Chakos, City of Berkeley, Berkeley, California
Donald H. Cheu, Kaiser Permanente, South San Francisco, California
Tom Durham, Central United States Earthquake Consortium, Memphis, Tennessee
Jerry A. Foster, ISO Commercial Risk Services, Inc., Scottsdale, Arizona
Edward Fratto, New England States Emergency Consortium, Wakefield, Massachusetts
Steven French, Georgia Institute of Technology, Atlanta, Georgia
Steve Ganz, Western States Seismic Policy Council, San Francisco, California
Alan Goldfarb, Berkeley, California
Jack Harrald, George Washington University, Washington, D.C.
Thomas Kinsman, City of Seattle, Construction & Land Use, Seattle, Washington
George Mader, Spangle Associates, Portola Valley, California
Shirley Mattingly, FEMA Region 9, San Francisco, California
Kent Paxton, San Mateo Area Office Emergency Services, Redwood City, California
John Smith, Massachusetts Emergency Management Agency, Framingham, Massachusetts
Douglas Smits, City of Charleston, Charleston, South Carolina
J. Carl Stepp, Austin, Texas
Gerry Uba, Emergency Management Program, Metro, Portland, Oregon

Earthquake Loss Estimation Methodology Assessments, Development and Calibrations

Risk Management Solutions, Inc., Menlo Park, California

Scott Lawson, Project Manager; Mourad Bouhafs, Software Manager; Fouad Bendimerad, Jawhar Bouabid, Foued Bouhafs, Jason Bryngelson, Weimen Dong, Dina Jabri, Guy Morrow, Hemant Shah, Chessy Si, Pane Stojanovski

Consultants

Charles Kircher, Technical Manager, Kircher & Associates, Mountain View, CA; Thalia Anagnos, Assistant Project Manager, and Guna Selvaduray, San Jose State University, San Jose, CA; Chris Arnold, Building Systems Development, Palo Alto, CA; Nesrin Basoz, K2 Technologies Inc; Catalino Cecilio and Martin McCann, Jack Benjamin & Associates; Hal Cochrane, Mahmoud Khater, EQE; John Mander, SUNY Buffalo; John McKean, Jerry Steenson and Bob Young, Colorado State University; Bryce Connick, Tom Desmond, John Eidinger, Bruce Maison and Dennis Ostrom, G&E Engineering, Oakland, CA; John Egan and Maurice Power, Geomatrix, San Francisco, CA; Gerald Horner, Horner & Associates; Onder Kustu, Oak Engineering, Belmont, CA; Gregory Luth and John Osteraas, Failure Analysis Associates, Menlo Park, CA; Farzad Namien, Consultant; Aladdin Nassar, Consultant; Jeanne Perkins, Association of Bay Area Governments, Oakland, CA; Claire Rubin, Claire Rubin & Associates, Arlington, VA; Jean Savy, Lawrence Livermore Laboratory; Paul Sommerville, Woodward-Clyde, Pasadena, CA; Federico Waisman, EQE; Fred Webster, Consultant, Menlo Park, CA; Felix Wong, Weidlinger Associates

California Universities for Research in Earthquake Engineering

A. H-S Ang, University of California, Irvine, CA; Jonathan Bray, Armen Der Kiureghian, Jack Moehle, Raymond Seed and Brady Williamson, University of California, Berkeley, CA; Peter Gordon, Harry Richardson, University of Southern California, Los Angeles, CA; David Keefer, U.S. Geological Survey, Menlo Park, CA; Anne Kiremidjian, Helmut Krawinkler and Haresh Shah, Stanford University, Stanford, CA

Portland Pilot Study

Dames & Moore, Inc.

Seattle, Washington: C.B. Crouse, Project Manager; Donald Ballantyne, Project Manager; Linda Noson, Assistant Project Manager; William Heubach, Greg Lammers, Eugene Trahern, Kenneth Winnick San Francisco, California: Jim Hengesh; Los Angeles, California: Alan Porush; Portland, Oregon: Douglas Schwarm; Santa Ana, California: Craig Tillman

Consultants

Carl Batten, ECO Northwest, Portland, OR; James Beavers, Mitigation Solutions Technology, Inc., Oakridge, TN; Grant Davis, KPFF Consulting Engineers, Portland, OR; Matthew Katinsky and John Schlosser, Schlosser & Associates, Seattle, WA

Boston Pilot Study

EQE International

Irvine, California: Ron Eguchi, Principal-in-Charge, Paul Flores, Project Manager, Ted Algermissen, R. Augustine, Neil Blais, Don Ballantyne, Stephanie Chang, Kenneth Campbell, Ronald Hamburger, Jim Johnson, Mayasandra Ravindra, Tom Roche, Michael Rojanski, Charles Scawthorn, Hope Seligson, Solveig Thorvald; New Hampshire: Paul Baughman, James White

Consultant

Sam Liao and Steve Line, Parsons Brinckerhoff, Boston, MA; Adam Rose, Penn State University, University Park, PA

Federal Emergency Management Agency, Mitigation Directorate, Washington, D.C.

Margaret Lawless, Program Assessment and Outreach Division Director (1998-present);, Cliff Oliver, Program Policy and Assessment Branch Chief (1998-present);, Gil Jamieson, Risk Assessment Branch Chief (1994 -1998);, John Gamble, Program Development Branch Chief (1992 - 1993);, Claire Drury, Project Officer (1996 - present);, Fred Sharrocks, Project Officer (1994 - 1996);, Michael Mahoney, Project Officer (1992 - 1993);, Stuart Nishenko (1998 - present).

U.S. Geological Survey, Reston, Virginia

Paula Gori (1995 - 1998), John Filson (1992 - 1993)

National Institute of Building Sciences, Washington, D.C.

Philip Schneider, Director, Multihazard Loss Estimation Methodology Program; Bruce E. Vogelsinger, Vice-President; John Boyer, Project Manager; Barbara Schauer, Project Manager; Baldev Sikka, Administrative Assistant

What is New in HAZUS99?

- The ground motion model has been revised by implementing new algorithms for calculating the distance to the fault rupture plane and accounting for earthquakes that rupture across multiple fault segments. New attenuation functions have been added for Hawaii (Munson & Thurber) and the Eastern United States (Lawrence Livermore National Lab). Details of these changes are included in Chapter 4 of the *Technical Manual*.

- A new bridge model based on the nonlinear performance of bridges has been implemented along with a revised bridge classification scheme and updated national bridge inventory. Details of these changes are included in Chapter 7 of the Technical Manual.

- For the probabilistic analysis of building damage, revised fragility curves have been added that are compatible with the USGS probabilistic ground motion maps. These new fragility curves, however, are still under review by the Earthquake Committee. In addition, **HAZUS99** now has the capability to automatically compute annualized loss estimates for buildings. Details of these changes are included in Chapters 5 and 16 of the *Technical Manual*.

- HAZUS99 now includes a network analysis model for potable water systems. Although the model is fully functional, the results generated are still under review by the Utility Lifeline Subcommittee. Details of these changes are included in Chapter 8 of the *Technical Manual*.

- The indirect economic loss model has been improved to accommodate weekly and monthly inputs in the first two years after an earthquake event. Details of these changes are included in Chapter 16 of the *Technical Manual*.

- **HAZUS99** includes a new application that can directly link **HAZUS** with Tri-NET. This capability will allow **HAZUS** to monitor Tri-NET and to automatically create a study region and execute the analysis when an earthquake is broadcast. In addition, **HAZUS99** response and recovery capabilities have been enhanced with the addition of a “ground truthing” option. This special feature allows users to incorporate observed damage information for use in post-event operational response. Details of these changes are included in Chapter 9 and 12 of the *User’s Manual*.

- **HAZUS99** has been optimized for greater speed.

- In addition to several new summary reports, a comprehensive summary report of analysis results has been added. The report, about 20 pages in length, contains text and tabular data about the study region, the earthquake scenario selected, and the results.

- The capability to save and recall map workspaces has been added.

- Several databases in HAZUS99 have been added: updated USGS probabilistic ground motion maps and US source maps, a revised hospital database, a new national bridge inventory, an updated hazardous material site database and a new national railroad track database.

Chapter 10
Induced Damage Models - Fire Following Earthquake

10.1 Introduction

Fires following earthquakes can cause severe losses. These losses can sometimes outweigh the total losses from the direct damage caused by the earthquake, such as collapse of buildings and disruption of lifelines. Many factors affect the severity of the fires following an earthquake, including but not limited to: ignition sources, types and density of fuel, weather conditions, functionality of water systems, and the ability of fire fighters to suppress the fires.

It should be recognized that a complete fire following earthquake model requires extensive input with respect to the level of readiness of local fire departments and the types and availability (functionality) of water systems. To reduce the input requirements and to account for simplifications in the lifeline module, the fire following earthquake model presented in this report is also simplified. In addition, while building upon past efforts, the model is still to be considered a technology which is in its maturing process. With better understanding of fires that will be garnered after future earthquakes, there will undoubtedly be room for improvement in our forecasting capability. The methodology, highlighting the Fire Following Earthquake component, is shown in Flowchart 10.1

10.1.1 Scope

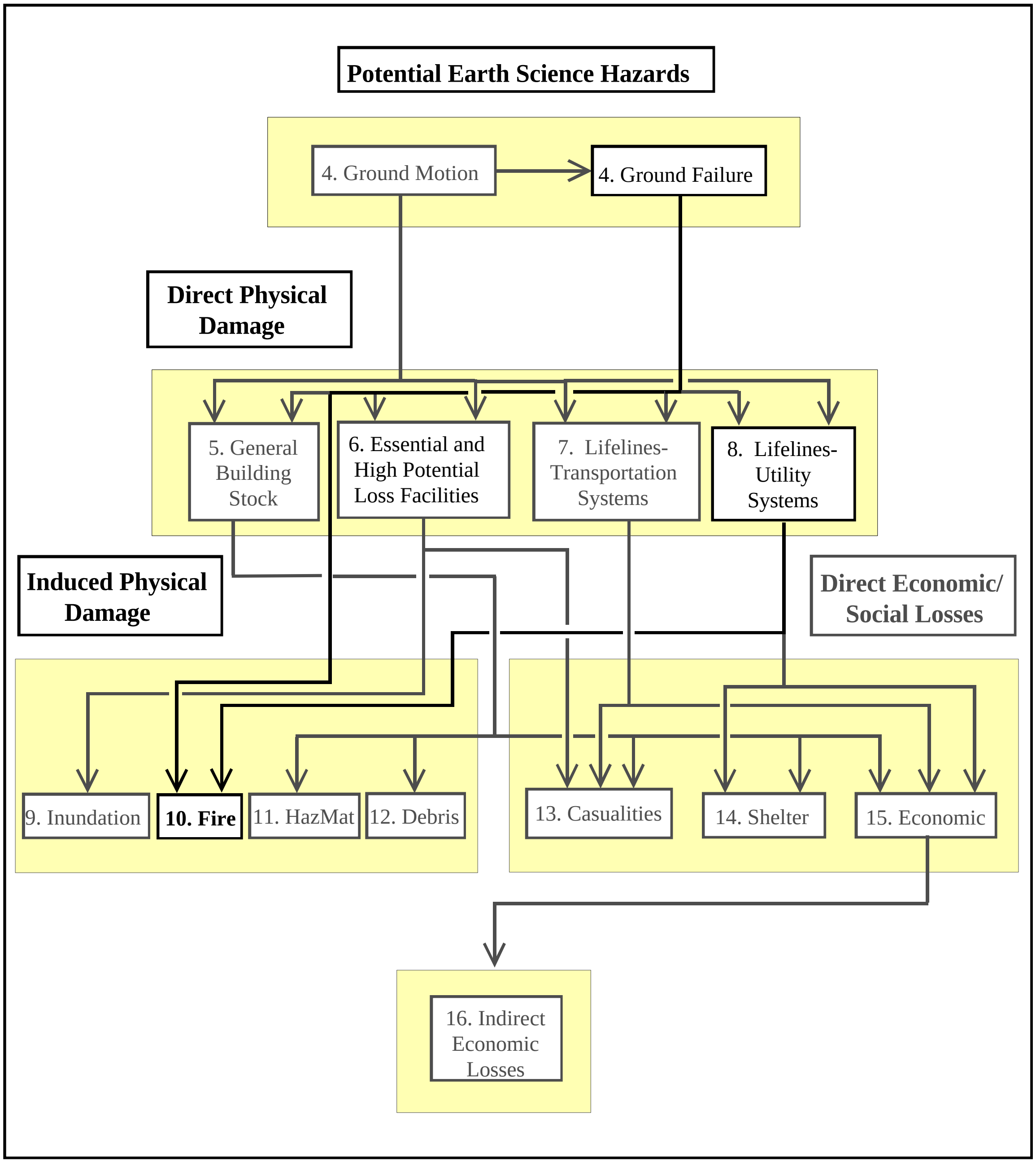
A complete fire following earthquake (FFE) model encompasses the three phases of a fire:

- ignition
- spread
- suppression

This methodology provides the user with the following estimates:

- Number of ignitions
- Total burned area
- Population exposed to the fires
- Building value consumed by the fire

Using Default and User-Supplied Data Analysis information will provide an estimate of the magnitude of the FFE problem, that could be used to plan for and estimate demands on local fire fighting resources.



Flowchart 10.1: Fire Following Earthquake Component Relationship to other Modules in the Earthquake Loss Estimation Methodology

10.1.2 Form of Damage Estimates

The FFE methodology provides the following:

- an estimate of the number of serious fire ignitions that require fire department response after a scenario earthquake
- an estimate of the total burned area
- an estimate of the population and building exposure affected by the fire

By applying the FFE module for several scenario earthquakes, representing different potential earthquakes for the study area, with different recurrence intervals, the user can examine the efficacy of certain pre-earthquake actions that can be used to mitigate the potential losses from fires in future earthquakes. For example, the user could study the effect of building more fire stations; adding more fire apparatus; improving immediate post-earthquake response to detect fires and suppress fires before they spread or seismically upgrading the water system. Since all these activities cost money, the user could study which combination of activities is most effective for their communities.

10.1.3 Input Requirements

This section describes the inputs required and output provided by the FFE module.

Input for Analysis:

Provided as general building stock inventory data:

- Square footage of residential single family dwellings (SFD)
- Square footage of residential non-SFD
- Square footage of commercial buildings
- Square footage of industrial buildings

Provided as essential facility inventory data:

- Number of fire stations
- Number of engines at each fire stations
- Geographical location of each station

Provided by the PESH module:

- PGA

Analysis options input by the user:

- Wind speed
- Wind direction
- Speed of the fire engine truck (after earthquake)
- Number of Simulations
- Maximum Simulation Time
- Simulation Time Increment

Multiple estimates for the same scenario earthquake are calculated by simulating fire following earthquakes several times. Hence, the user needs to provide the number of simulations that should be performed in order to come up with average estimates from independent simulations. It is suggested that the user try 6 to 10 simulations. The maximum time after the earthquake for which the simulation should be performed and the time increment for each simulation are also user inputs. For example, a resonable maximum time could be 10,000 minutes when all the fires could possibly be suppressed. It is suggested that a time increment of 1 to 15 minutes be provided for sufficiently accurate simulations.

10.2 Description of Methodology

10.2.1 Ignition

The first step in evaluating the potential losses due to fires following earthquake is to estimate the number of fires that actually occur after the earthquake. The ignition model is based on the number of serious FFEs that have occurred after past earthquakes in the United States.

The term "ignition" refers to each individual fire that starts (ignites) after an earthquake that ultimately requires fire department response to suppress. Thus, a fire that starts after an earthquake but which is put out by the occupants of the building without fire department response is not considered an ignition for purposes of this model. Fires that are put out by building occupants are usually those discovered very early and are put out before they can do substantial damage. These ignitions do not lead to significant losses.

In a fire ignition model previously developed by Scawthorn (1987), the number of FFEs was established by counting the actual FFEs versus the inventory exposed to equal levels of MMI (Modified Mercalli Intensity). The model did not include fire data from more recent and well documented earthquakes, such as the 1989 Loma Prieta event. For this methodology, the model has been re-calibrated. The prediction parameter (MMI) and output parameter (number of ignitions per thousand Single Family Equivalent Dwellings (SFEDs)), have not been carried forward in this project. (One SFED is defined to be 1,500 square feet of floor area.)

The calibration process has been performed in three steps:

- The database of actual earthquake experience was expanded by incorporating new data points representing the fire ignitions from the 1989 Loma Prieta earthquake.
- The ignition per SFED scale was changed to ignitions per 1,000,000 square feet of structure inventory.
- The MMI scale was converted to the PGA scale as shown in Table 10.1.

Table 10.1: MMI to PGA Conversion Table

MMI	VI	VII	VIII	IX	X	XI	XII
PGA	0.12	0.21	0.36	0.53	0.71	0.86	1.15

Table 10.2 provides the results after performing the calibration. This table provides the database of fire ignitions from past United States earthquakes, calibrated to ignitions per 1,000,000 square feet, and as predicted using PGA.

Figure 10.1 is a plot of the information found in Table 10.2. As can be seen from the plot, there is considerable scatter in the empirical evidence. The reasons for this scatter include the following:

- The horizontal axis is based upon historical interpretations of MMI scale value processed through an MMI to PGA conversion. Different investigators will sometimes rate a specific area with different MMI values, sometimes differing by one or two intensities. This introduces large uncertainties. Also, the MMI to PGA conversion process builds in more uncertainty. For example, the same PGA values at rock and at soft soil sites can produce different levels of damage, particularly if liquefaction or landslides occur.

- The quantification of the actual number of fire ignitions in past earthquakes is most often based on conflicting data sources. The usual sources base some estimates on journals and newspaper accounts, which often conflict. More recent efforts have tracked down each fire ignition using fire incident reports from fire departments, and these data are more reliable.

- Fire ignitions are probably not related to a single input parameter, whether it be MMI or PGA. Actual fire ignitions start for a number of reasons, including:
    - Toppling over of unanchored items (this is PGA-related), causing short circuits or fuel spills. This causes fires if an ignition source (spark) is present.
    - Breakage of underground utilities (such as gas lines) which provides a fuel source for the ignition. This is PGD-related.
    - Interstory drift of structures, which may cause short circuits in electrical wiring. This is related to PGA and age of structure / wiring condition.
    - Time of day. During meal times, more electrical and gas appliances are in use. This would allow for more potential for ignitions than if the earthquake occurred during night-time hours. Similarly, time of year is important in that many gas or oil appliances are used in winter for home heating. [Note: time of year is an important factor for fire spread given an ignition, in that fire growth is dependent upon heat.]

A second order fit of the data provides the following ignition model:

$$\text{Ignitions} = -0.025 + (0.592 * \text{PGA}) - (0.289 * \text{PGA}^2) \tag{10-1}$$

Table 10.2 Fires Following United States Earthquakes (1906 - 1989)

City, Year of Earthquake	PGA (g)	Intensity (MMI)	Ignitions	Ignitions per 1,000,000 Sq. Feet
Coalinga 1983	0.36	VIII	1	0.30
Daly City 1989	0.12	VI	3	0.05
Anchorage 1964	0.71	X	7	0.24
Berkeley 1906	0.44	VIII-IX	1	0.16
Berkeley 1989	0.07		1	0.013
Burbank 1971	0.21	VII	7	0.16
Glendale 1971	0.15	VI-VII	9	0.13
Los Angeles 1971	0.15	VI-VII	128	0.09
Los Angeles 1933	0.15	VI-VII	3	0.01
Long Beach 1933	0.53	IX	19	0.26
Marin Co. 1989	0.12	VI	2	0.02
Morgan Hill 1984	0.21	VII	4	0.40
Mountain View 1989	0.21	VII	1	0.02
Norwalk 1933	0.28	VII-VIII	1	0.05
Oakland 1906	0.44	VII-IX	2	0.06
Oakland 1989	0.07		0	0.00
Pasadena 1971	0.21	VII	2	0.04
San Francisco 1989	0.21	VII	27	0.08
San Francisco 1906	0.44	VII-X	52	0.26
San Francisco 1957	0.12	VI	0	0.00
San Fernando 1971	0.53	IX	3	0.37
San Jose 1984	0.36	VIII	5	0.02
San Jose 1906	0.36	VIII	1	0.08
Santa Clara 1906	0.44	VIII-IX	1	0.22
Santa Cruz 1989	0.36	VIII	1	0.04
Santa Cruz Co. 1989	0.28	VII-VIII	24	0.03
San Mateo Co. 1906	0.36	VIII	1	0.14
Santa Rosa 1969	0.36	VIII	1	0.06
Santa Rosa 1906	0.71	X	1	0.18
Whittier 1987	0.28	VII-VIII	6	0.10

Figure 10.1 also shows the best fit curve using equation 10-1. The correlation between PGA and number of ignitions in the fitting is quite low. This confirms that PGA is by itself not a perfect indicator of fire ignitions. This result is not too surprising, given the uncertainties involved in the collection of the empirical data and in the ways fires start.

Timing of Ignitions

The number of ignitions that are predicted using the above ignition model are based on empirical results, and include fires attributed to the earthquake, both starting immediately after the earthquake and starting some time after the earthquake.

Based upon the empirical record, and using judgment, it is estimated that about 70 percent of all fire ignitions start immediately after the earthquake. "Immediately" means that the fire ignition is discovered within a few minutes after the earthquake.

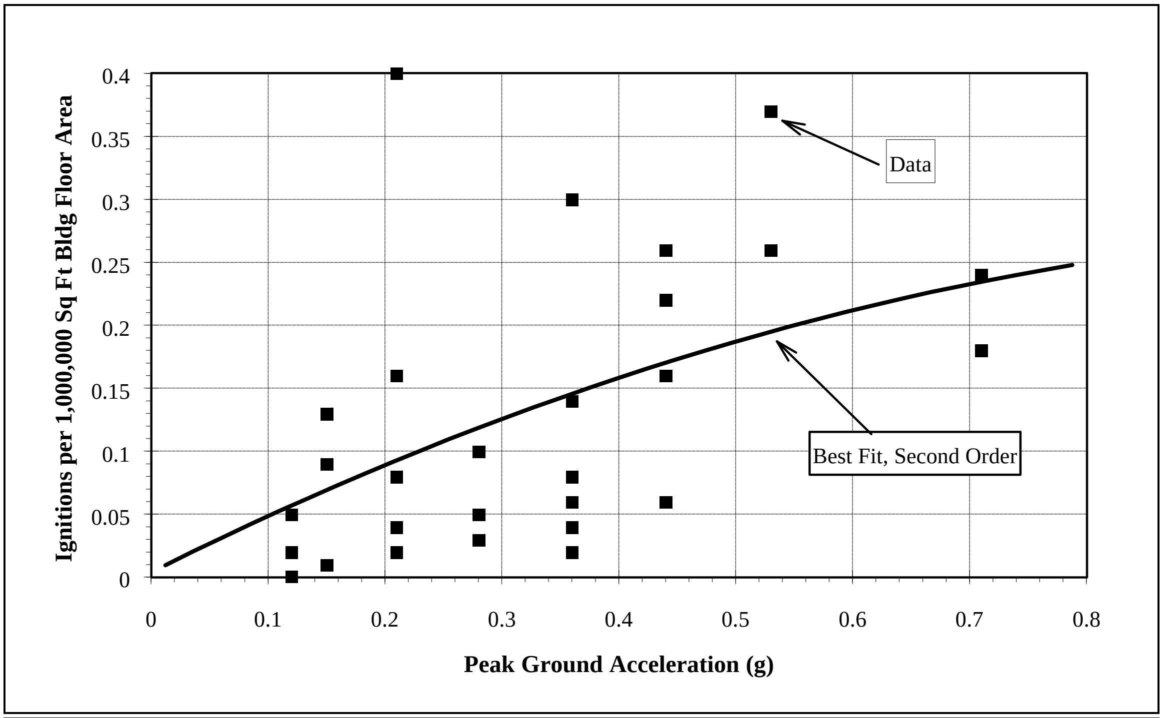


Figure 10.1 Fire Ignitions in United States Earthquakes (1906-1989).

The remaining ignitions start sometime after the earthquake, ranging from an hour to possibly a day or so after the earthquake. A typical cause of these later ignitions is the restoration of electric power. When power is restored, short circuits that occurred due to the earthquake become energized and can ignite fires. Similarly, when power is restored, items which have overturned, fallen onto range tops, etc., can ignite. If no one is present at the time electric power is restored, fire ignitions requiring fire department response can occur.

10.2.2 Spread

The second step in performing the FFE analysis is to estimate the spread of the initial fire ignition. The following description of fire spread in urban areas is based on a model developed by Hamada (1975). Hamada developed a model for fire spreading for urban Japan. His model is described as follows:

$$N_{tV} = \frac{1.5d}{a^2} * K_s * \left(K_d + K_u\right) \tag{10-2}$$

where:

$N_{t\,V}$ = Number of structures fully burned
t = time, in minutes after initial ignition
V = wind velocity, in meters per second
δ = "Built-upness" factor, dimensionless, described below
a = average structure plan dimension, in meters
d = average building separation, in meters
K_s = half the width of fire from flank to flank, in meters
K_d = length of fire in downwind direction, from the initial ignition location, in meters
K_u = length of fire in upwind (rear) direction, from the initial ignition location, in meters

$$d = \frac{\sum_{i=1}^{n} a_i^2}{\text{Tract Area}} \tag{10-3a}$$

where:

a_i = plan dimension of building i
n = number of structures

$$K_d = \frac{(a+d)}{T_d} * t \tag{10-3b}$$

$$K_s = \left(\frac{a}{2}+d\right) + \frac{(a+d)}{T_s}\left(t - T_s\right) \quad ; \quad K_s \geq 0 \tag{10-3c}$$

$$K_u = \left(\frac{a}{2}+d\right) + \frac{(a+d)}{T_u}\left(t - T_u\right) \quad ; \quad K_u \geq 0 \tag{10-3d}$$

$$T_d = \frac{1}{1.6\left(1+0.1V+0.007V^2\right)}\left[\left(1-f_b\right)\left(3+0.375a+\frac{8d}{25+2.5V}\right) + f_b\left(5+0.625a+\frac{16d}{25+2.5V}\right)\right] \tag{10-3e}$$

$$T_s = \frac{1}{1+0.005V^2}\left[\left(1-f_b\right)\left(3+0.375a+\frac{8d}{5+0.25V}\right)+f_b\left(5+0.625a+\frac{16d}{5+0.25V}\right)\right] \tag{10-3f}$$

$$T_u = \frac{1}{1+0.002V^2}\left[\left(1-f_b\right)\left(3+0.375a+\frac{8d}{5+0.2V}\right)+f_b\left(5+0.625a+\frac{16d}{5+0.2V}\right)\right]$$

(10-3g)

where:

$$f_b = \frac{\text{Number of fire resistant buildings}}{\text{All buildings}}$$

A discussion of the Hamada model follows.

- It is assumed that an urban area is represented by a series of equal square (plan area) structures, with equal spacing between structures. The plan dimension of the average structure is denoted "a", and hence the plan area is a^2.

- It is assumed that the spaces between structures in a subdivision can be represented by an average separation distance, d. For purposes of this model, the separation distance represents the typical distance between structures within a single block. This distance accounts for side yards, backyards and front yards, but does not include streets and sidewalks.

- The "built-upness", or building density ratio δ is defined by equation 10-3a. To put this building density ratio in context, a value of 0.35 represents a densely built area, and a value of 0.10 represents an area which is not very densely built.

- Figure 10.2 shows the fire spread in terms of ovals, which is the usual case of fires burning through an evenly distributed fuel load, with constant wind velocity. In the actual urban conflagrations, fires exhibit this trend initially, but the final shape of the fire spread differs, as different fuel loads are experienced, as wind shifts, and as different fire suppression actions take place. The fire burn area is approximated as the product of the downwind fire spread plus the upwind fire spread (K_d + K_u) times the width of the fire spread ($2K_s$).

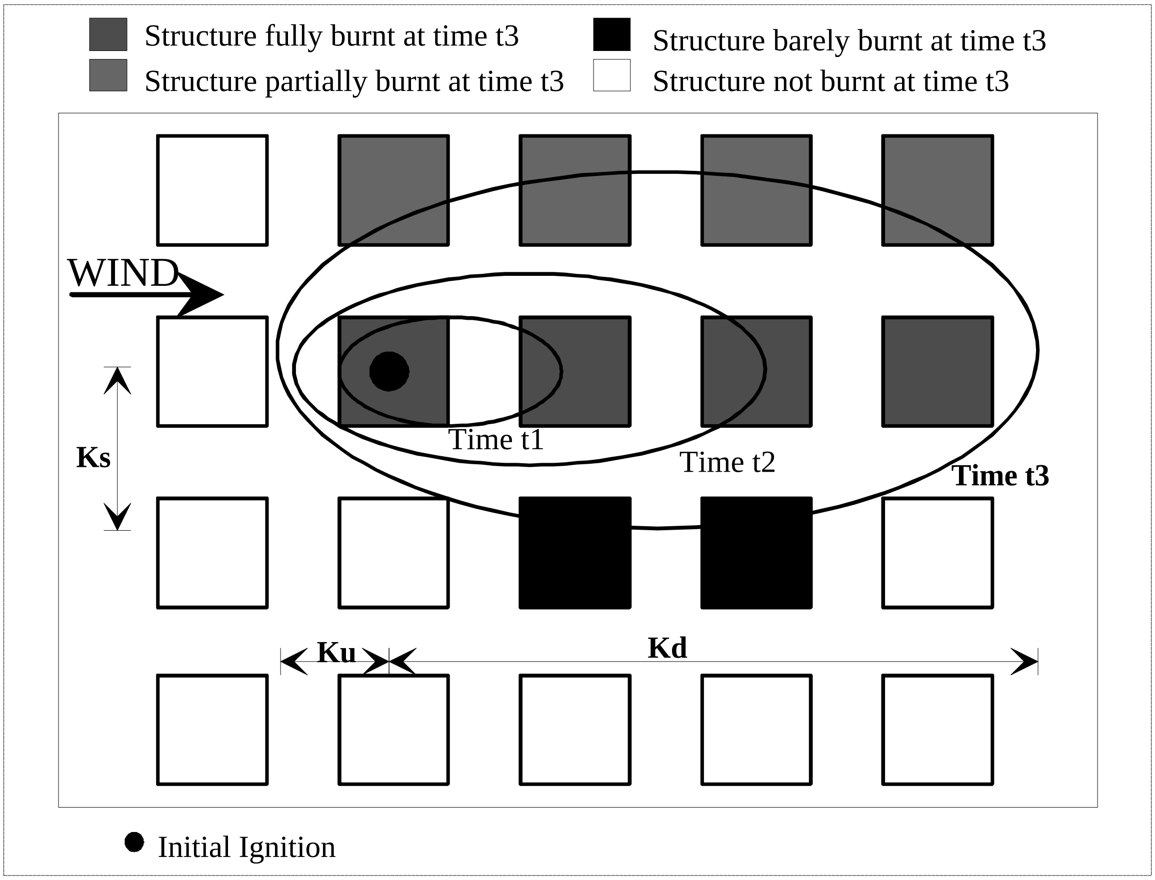


Figure 10.2 Fire Spread Process.

- The fire spread model accounts for the speed of advance of the fire considering the following variables:

  - **Direction of spread**. The speed of advance of the fire is highest in the downwind direction, slower in the side wind direction, and slowest in the upwind direction.
  - **Wind velocity**. The speed of advance of the fire increases as the square of the wind velocity.
  - **Fire resistance of structures**. The speed of advance through wood structures is about twice the speed of advance through fire resistant structures.

It should be noted that the Hamada model results in different fire spreading rates in the downwind, sidewind, and upwind directions even for zero wind speed. To correct this problem, a linear interpolation function is introduced which forces the fire spreading rates to be equal in all directions as the wind speed approaches zero. For wind speeds less than 10 m/sec, the adjusted fire spreading rates (K_d', K_u' and K_s') are given as follows:

$$K_d^{'} = K_d\left(\frac{V}{10}\right) + \sqrt{\left(\frac{K_d + K_u}{2}\right)K_s}\left(1 - \frac{V}{10}\right) \tag{10-4a}$$

$$K_u' = K_u\left(\frac{V}{10}\right) + \sqrt{\left(\frac{K_d + K_u}{2}\right)K_s}\left(1 - \frac{V}{10}\right) \qquad (10\text{-}4b)$$

$$K_s' = K_s\left(\frac{V}{10}\right) + \sqrt{\left(\frac{K_d + K_u}{2}\right)K_s}\left(1 - \frac{V}{10}\right) \qquad (10\text{-}4c)$$

10.2.3 Suppression

The term suppression is defined as all the work of extinguishing a fire, beginning with its discovery. The steps in the suppression activity are defined as follows:

- **Discovery Time**. Elapsed time from the start of the fire until the time of the first discovery which results directly in subsequent suppression action.
- **Report Time**. Elapsed time from discovery of a fire until it is reported to a fire agency that will respond with personnel, supplies and equipment to the fire.
- **Arrival Time**. Elapsed time from the report time until the beginning of effective work on a fire.
- **Control Time**. Elapsed time from the beginning of effective work on a fire to when the fire is controlled.
- **Mop-up Time**. Elapsed time from completion of the controlling process until enough mop-up has been done to ensure that the fire will not break out and the structure is safe to re-occupy.

10.2.3.1 Discovery Time

The time to discover a fire is usually on the order of a few minutes if anyone is present to observe the fire. In modern urban areas, many structures have smoke detectors, and these will alert occupants or perhaps people nearby the structure that a fire has ignited. The following discovery model is used:

- 85 percent of structures are occupied at the time of the earthquake. In these structures, fires are discovered randomly between 0 and 5 minutes.
- 15 percent of structures are not occupied at the time of the earthquake. In these structures, fires are discovered randomly between 3 and 10 minutes.

10.2.3.2 Report Time

The time to report a fire is usually less than one minute under non-earthquake conditions. Most people report a fire directly to the fire department or call 911. The 911 dispatchers determines the degree of the emergency and notify the fire department.

After an earthquake, this usual method to report fires will be hampered, either due to phone system overload (inability to get a dial tone) or due to physical damage to various parts of the phone system. In theory, the fire model could account for the various levels of phone system damage from outputs from the communications module. However, for simplification the report time aspects are based on the following methods.

Five different methods are considered in determining how the fire will actually be reported to the fire department after an earthquake.

- **Cellular phone**: The model assumes that 15 percent of all fires can be reported by cellular phone taking 1 minute.
- **Regular phone**: The model assumes that 25 percent of all fires can be reported by regular phone taking 1 minute; 50 percent of all fires can be reported by regular phone, taking anywhere from 1 to 5 minutes; and 25 percent of all fires cannot be reported by regular phone.
- **Citizen alert**: In all fires, one option to report fires is for the resident to walk or drive to the nearest fire station and report the fire. This method of reporting is available for all fire ignitions. The time to report such a fire is anywhere from 1 to 11 minutes.
- **Roving Fire Vehicle**: A fire department practice for fire response after earthquakes is to immediately get fire apparatus onto the streets, looking for fires. The model assumes that a roving vehicle can detect a fire somewhere between 3 and 14 minutes after the earthquake.
- **Aircraft**: In many post-earthquake responses, helicopters and other aircraft will be flying over the affected areas. Often by the time a fire is spotted at height, it has already grown to significant proportions. The model assumes that fires can be detected by aircraft anywhere from 6 minutes to 20 minutes after the earthquake.

The model considers all five methods to report fires. The method which results in the earliest detection is the one which is used in the subsequent analysis.

10.2.3.3 Arrival Time

The arrival time is the time it takes after the fire is reported for the first fire suppression personnel and apparatus to arrive at a fire ignition. Under non-earthquake conditions, fire engines respond to fires by driving at about 30 miles per hour on average. After an earthquake, it is expected that fire engines will have a somewhat more difficult time in arriving at a fire due to damage to the road network, debris in the streets due to fallen power poles or damaged structures, traffic jam caused by signal outages, and the like.

The model accounts for this slowdown in arrival time as follows:

- If the fire was detected by a roving fire engine, arrival time is 0 minutes (the engine is already at the fire).
- If the fire is called in or reported by citizens, the time for the first engine from a local fire department to arrive at the fire is between 2 and 12 minutes. (Under

non-earthquake conditions, arrival time is usually about 1 - 6 minutes, so the model assumes that the fire engines drive at 50 percent of normal speed).

10.2.3.4 Control Time

The time and resources needed to control the fire will depend upon the status of the fire at first arrival of the first fire engine. The model accounts for different control times considering the status of the fire. Since the status of a fire can vary over time, the model continues to check fire status every minute.

10.2.3.4.1 Room and Contents Fires

If the total time from ignition to arrival is short, then the fire may be still a "room and contents" fire. These fires are small, and most fire engines carry enough water in the truck to control them. (Typical water carried in a pumper truck is 500 gallons to 1000 gallons). If this is the case, the model assumes that the first responding fire engine can control the fire. The engine is held at the location of the fire for 10 minutes. Thereafter, the engine is released for response to other fires that may be ongoing.

10.2.3.4.2 Structure Fires - Engines Needed

If the fire has spread to beyond a room and contents fire, then suppression activities require two resources: an adequate number of fire apparatus (engine trucks, ladder trucks, hose trucks) and personnel, and an adequate amount of water.

Most fire apparatus today are engine trucks, and the model does not differentiate between the capabilities of a ladder truck and an engine truck. (The user should input to the model the sum of fire department apparatus which can pump water at a rate of about 1,000 gpm to 2,000 gpm. Hose tenders without pumps, search and rescue trucks, and automobiles are not counted as available apparatus in the model).

The model determines the number of required trucks as follows:

- Single Family Residential Fires. Figure 10.3 shows the number of fire trucks needed to suppress a fire, versus the number of structures already burned.
- Other Fires. Figure 10.4 shows the number of fire trucks needed to suppress a fire, versus the number of structures already burned, for the case when the original ignition was at a structure other than a single family building. These ignitions include fires at apartment, commercial, wholesale and industrial structures. From Figure 10.4, it is shown that a minimum of two trucks are needed if the burnt structures range from zero to four. Since only one truck is sent to each fire, this leads to all fires becoming a conflagration, regardless of size. A modification is introduced by modifying the requirement to:

    - One truck is needed if the burnt structures are less than 2.
    - Two trucks are needed if the burnt structures are between 2 and 4.

This modification will reduce the total burnt area since all fires close to the fire stations will be controlled and putout by only one engine.

10.2.3.4.3 Structure Fires - Water Needed

Except in the case of room and content fires, urban fire suppression usually requires large quantities of water in order to gain control. (The issue of firebreaks in urban areas is described later). The amount of water needed is usually expressed in two terms:

- **Required Flow**: This is the amount of water needed to fight a fire from one or more fire hydrants, usually expressed in gallons per minute, gpm.
- **Required duration**: This is the length of time the fire flow is needed, in hours (or minutes).

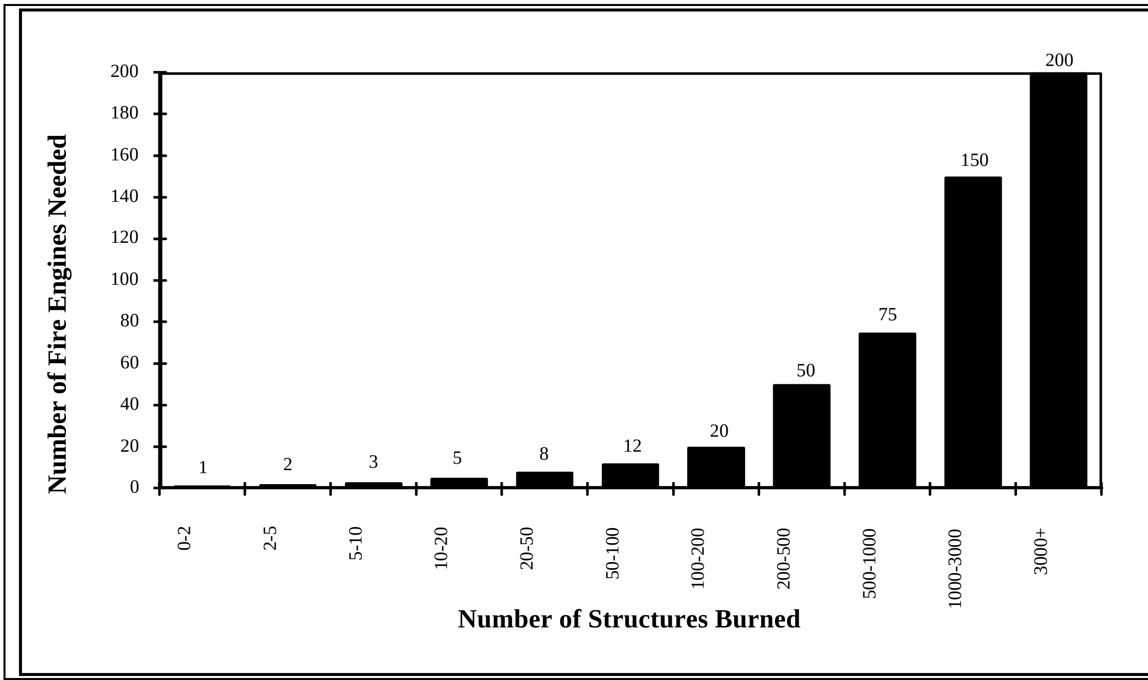


Figure 10.3 Ignitions That Start in Single Family Structures.

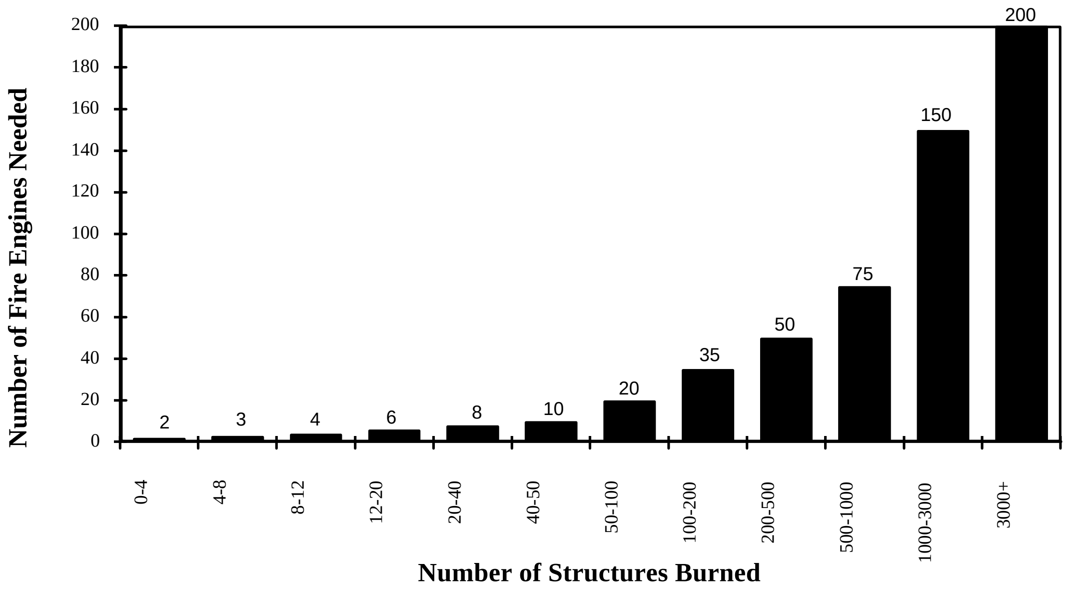


Figure 10.4 Ignitions That Start in Non-Single Family Structures.

A term often used in describing water needs is pressure. In the usual fire fighting terminology, the fire flows are required at the hydrant outlet at a minimum of 20 psi residual pressure while the hydrant is flowing.

Most cities use a water distribution system that delivers water for customer needs (drinking, sanitary, and other uses) and water for fire flow needs through a single set of pipes. Water pressures are usually kept in the mains at around 40 psi - 60 psi to meet normal customer needs. When a hydrant is opened, flows through the water mains increase. In areas of the city where mains are not highly interconnected (such as in hillside communities) or where mains have small diameters (2", 4" and some 6" pipes), the high velocities of water needed to deliver the water to the fire hydrant cause significant pressure drops. If the water pressure drops below about 20 psi, then fire engines have a difficult time drafting the water out of the hydrant.

The water needed to fight a fire at any given time t (W_t in gallons), depends upon the extent of the fire. The following equations are used to calculate the water needed:

$$W_t = 1250\left(N_{tV}\right)^{0.4} \quad ; \quad 0 < N_{tV} \leq 3000 \qquad (10\text{-}5)$$

where N_{tV} = Number of structures burned at time t, at wind velocity V

Equation (10-5) is based upon the Uniform Fire Code (1991) for single structure fires (N_{tV} = 1) and modified for large conflagration fires.

For apartment fires, the amount of water needed is somewhat higher than the water needed for a single family residence, and is expressed in equations 10-6 and 10-7:

$$W_t = 1500\left(N_{tV}\right)^{0.5} \quad ; \quad 0 < N_{tV} \le 4 \tag{10-6}$$

or,

$$W_t = 3000 + 1250\left(N_{tV} - 4\right)^{0.4} \quad ; \quad 4 < N_{tV} \le 3000 \tag{10-7}$$

For commercial, wholesale and industrial fires, the amount of water needed is higher than the water needed for a small apartment building, and is expressed in equations 10-8 and 10-9:

$$W_t = 2500\left(N_{tV}\right)^{0.5} \quad ; \quad 0 < N_{tV} \le 4 \tag{10-8}$$

or,

$$W_t = 5000 + 1250\left(N_{tV} - 4\right)^{0.4} \quad ; \quad 4 < N_{tV} \le 3000 \tag{10-9}$$

For petroleum fires, the amount of water needed is higher than the water needed for other types of fires, and is expressed in equations 10-10 and 10-11:

$$W_t = 4000\left(N_{tV}\right)^{0.5} \quad ; \quad 0 < N_{tV} \le 4 \tag{10-10}$$

or,

$$W_t = 8000 + 1250\left(N_{tV} - 4\right)^{0.4} \quad ; \quad 4 < N_{tV} \le 3000 \tag{10-11}$$

For all types of fires, the duration of flow is determined by equation 10-12:

$$D = 0.5 * \left(\text{engines needed}\right)^{0.4} \tag{10-12}$$

where D = duration of flow needed, in hours

(engines needed) = taken from Figure 10.3 or 10.4

10.2.3.4.4 Engines Available

The number of fire apparatus (engines and ladders) available in the study area is supplied by the user as input to the model. The following information is needed:

- The number of pumper apparatus engines in every jurisdiction within the study area. The user must select the level of refinement of the jurisdiction within the study area. A jurisdiction can be set at either the fire station level, the battalion level, or the city level.
  - Jurisdictions can be set as a city if the city has population of about 400,000 people or less.

  - Jurisdictions should be set as a battalion (or more refined) if the city has population greater than about 400,000.

- The number of pumper apparatus available from mutual aid, from jurisdictions outside the study area. Mutual aid jurisdictions can usually be set in terms of the number of pumper apparatus available within a county. The geographic extent of the earthquake should be considered to decide what proportion of mutual aid that can be normally counted on will be delivered.

The model tracks the order of detection of the fires. Fire engines will serve fires which have been discovered first and are nearest to the fire stations. An insufficient number of fire trucks will result in the fire spreading faster which will be addressed later.

10.2.3.4.5 Water Available

The water available to fight a fire depends upon the capacity of the water distribution system, taking into account the level of damage to the system. Parameters that determine the amount of water available in a cell to suppress fires include:

- Available water flow
- Duration of water flow for pumped water system

10.2.3.4.6 Fire Spread with Partially Effective Suppression

For each fire, at each time step of the analysis, the model checks to see what is the available flow for fire suppression activities and what number of fire trucks are at the scene of the fire. Based upon the size of the fire at that time, the model calculates the number of fire trucks needed and the amount of water normally needed to control the fire. From these values, two ratios are calculated:

$$R_{truck} = \frac{\text{trucks at fire}}{\text{trucks needed at fire}}, \qquad \text{but } R_{truck} \text{ should not exceed 1.0}$$

$$R_{water} = \frac{\text{available flow at fire}}{\text{flow needed}}, \qquad \text{but } R_{water} \text{ should not exceed 1.0}$$

where,

available flow = (reduction factor) * (typical discharge from hydrant) * (number of hydrants to fight fire)

The reduction factor is set to the serviceability index obtained from Chapter 8. The typical discharge from a hydrant is around 1750 gallons/min. Finally, the number of hydrants available at the scene of the fire is estimated as follows:

No. of Hydrants = 1.5 * $(K_d+K_u)(2K_s)/(100*100)$

Where K_d, K_u, and K_s are previously defined. Note that 100 is the average spacing in meters between fire hydrants (typically, the spacing is in the range 60 m to 150 m). The coefficient 1.5 reflects the assumption of 50% of additional fire hydrants from adjacent blocks or equivalent will be available to fight the fire.

Based on the calculated values of R_{truck} and R_{water}, the fire suppression effectiveness is:

$$P_{effective} = \left(R_{truck} * R_{water}\right)^{0.7} \geq 0.33R_{truck} \quad (10\text{-}13)$$

This equation reflects the following logic. If the available trucks and water are much less than required, then there is good chance that the fire will spread. Conversely, if most of the trucks and water needed are available, then the fire suppression effectiveness is much better.

Due to fire suppression, the rate of fire spread will be slowed down and the reduced rate will be

$$\text{Spread Rate} = \text{Spread}_{\text{non-suppressed}} \cdot \left(1 - P_{effective}^{0.7}\right) \quad (10\text{-}14)$$

The Spread Rate is the key variable used in determining the spread of the fire. Equations 10-13 and 10-14 together provide the prediction as to the effectiveness of partial fire suppression in stopping urban conflagration.

10.2.3.4.7 Fire Spread at Natural Fire Breaks

Fire breaks are one of the ways to stop fires from spreading. Fire breaks abound in an urban area and include streets, highways, parks, and lakes. The model accounts for fire breaks as follows:

- Fires can spread within a city block following equation 10-3 as modified by equation 10-14. The model keeps track of the spread.

- The average city block is assumed to have two rows of houses, and there are 15 houses down a single side of a block. The average length of a city block is taken as the average of the width and length of the block. If the user does not supply the average width of a city block street, including sidewalks, then the model will use default width of 25 meters.

- The model assumes that every fifth fire break is three times wider than the average city street fire break. These wide fire breaks account for the presence of wide boulevards, interstate highways, parks and lakes.

- If the fire spread just reaches a fire break, then there is a probability that the fire break will control the fire, even with no active suppression or partial suppression ongoing. The probability of the fire jumping the fire break increases with the wind velocity, decreases with the width of the fire break, and decreases if there is active fire suppression as shown in Figure 10.5. Figure 10.5 is adapted from Dames and Moore, 1987, and combined with judgment.

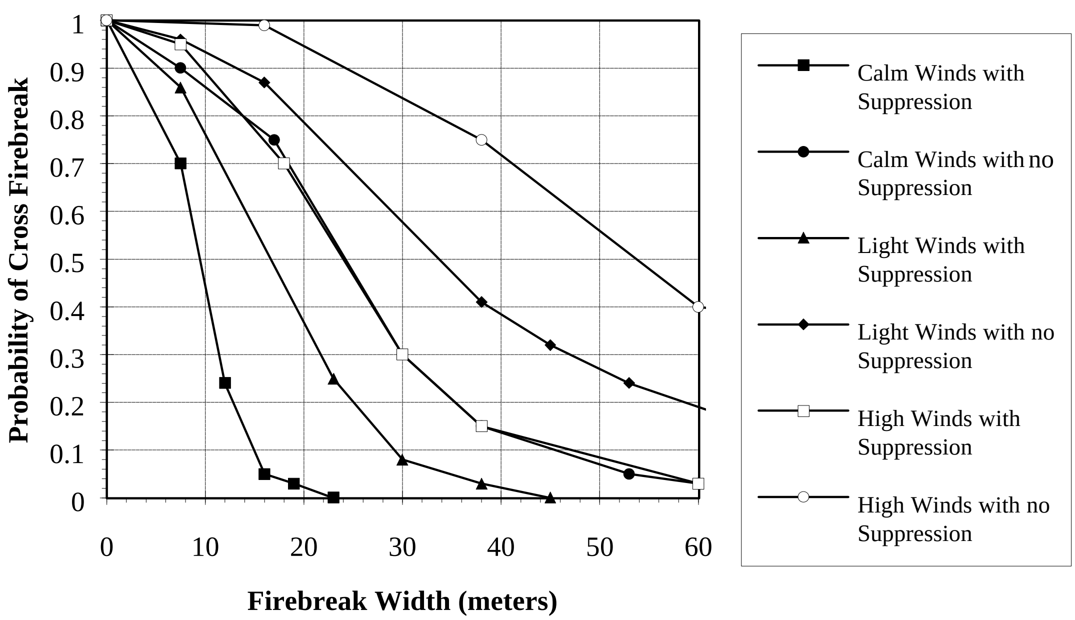


Figure 10.5 Probability of Crossing Firebreak.

10.3 Guidance for Expert-Generated Estimates

As described in Section 10.2, the FFE model makes several simplifying assumptions about the study area. Any or all of these assumptions can be relaxed, and the resulting FFE model will be more refined. The reader may adjust the model by relaxing the following assumptions:

- Analyze the actual water system, for each pressure zone. Many water systems are made up of dozens of pressure zones, many interdependent upon each other. With zone-by-zone information, the analysis can much better identify which parts of the study area are most prone to conflagration.

- Adjust the model for urban intermix fuels, if these conditions are applicable to the study area. Fire spreads are much higher in these areas than in urban areas. The analysis will have to digitize in the fuel mix for each cell of the model, and adjust the fire spread model accordingly.

- Add high flow water system boundaries to the model. In some areas of the city, the water system may be designed to provide very high flows: 24" diameter (or larger) transmission pipes (with hydrants) which carry flows on the order of 20,000 gpm or higher. If there are adequate fire department resources available, then almost any fire can be stopped at these locations, even under relatively high winds. Of course, the Water System Lifeline module will have to also be analyzed to determine if these pipes break under the earthquake.

10.4 References

Dames and Moore Report, March 1987. "Fire Following Earthquake, Estimates of the Conflagration Risk to Insured Property in Greater Los Angeles and San Francisco," Report to All-Industry Research Advisory Council, C. Scawthorn.

G&E Engineering Systems Inc., 1994. "Earthquake Loss Estimation, Technical Manual, Fire Following Earthquake", Prepared for the National Institute of Building Sciences, Principal Investigator: John M. Eidinger.

Hamada, M., 1975. "Architectural Fire Resistant Themes", No 21., Kenchikugaku Taikei, Shokokusha, Tokyo.

International Conference of Building Officials, Uniform Fire Code, 1991.

Chapter 11
Induced Damage Models - Hazardous Materials Release

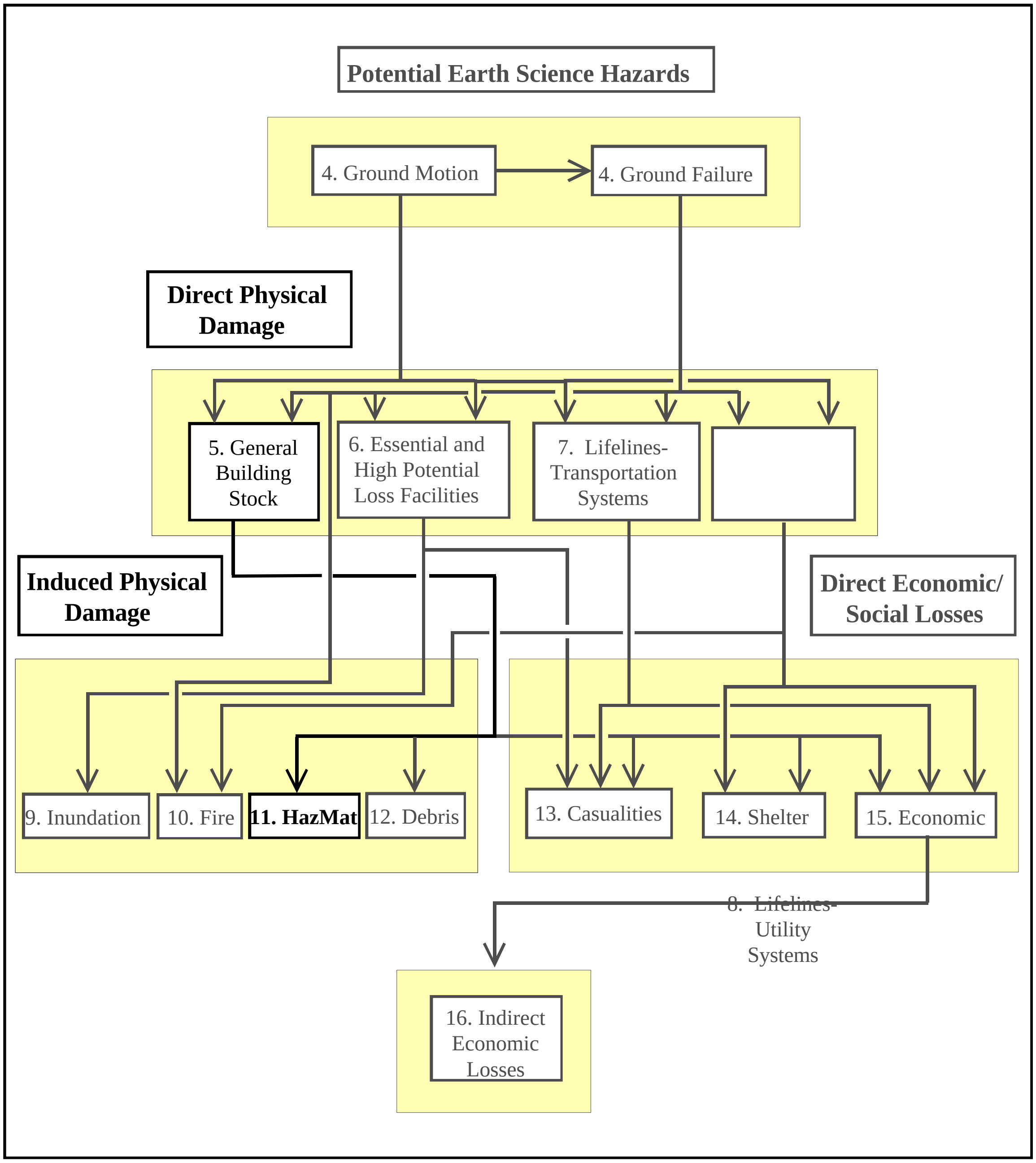
11.1 Introduction

Hazardous materials are those chemicals, reagents or substances that exhibit physical or health hazards, whether the materials are in a usable or waste state. The scale, and hence the consequences, of hazardous materials releases can vary from very small, such as a gallon of paint falling off of shelves, to regional, such as release of toxic chemicals from a processing plant. Most hazardous materials incidents have immediately led to human casualties only in cases where explosions have occurred. Non-explosive hazardous materials incidents, which comprise the vast majority, typically have led to contamination of the environment and temporary health consequences to human beings. Hazardous materials releases can also lead to fires. With specific reference to earthquake caused hazardous materials incidents, the data thus far indicate that there have been no human casualties. The consequences of these incidents have been fires and contamination of the environment, and have led to economic impacts because of the response and clean-up requirements. The methodology highlighting the Hazardous Materials Release component is shown in Flowchart 11.1.

11.1.1 Scope

This loss estimation methodology has been restricted to identifying the location of facilities that contain hazardous material which could lead to a significant immediate demand on health care and emergency response facilities. These types of incidents would include large toxic releases, fires or explosions. Thus, the default database of hazardous material facilites is limited to facilities where large quantities of chemicals that are considered highly toxic, flammable or highly explosive are stored. Estimates of releases that could cause pollution of the environment and the need for long-term clean-up effects are beyond the scope of this methodology.

An exhaustive search of the existing literature for models that can be utilized to predict the likelihood of occurrence of hazardous materials releases during earthquakes was conducted at the beginning of this study. Unfortunately, no directly usable models were found. There were three attempts at modeling that had been made previously (Tierney, et al., 1990, Ravindra, 1992, Los Angeles County Fire Department, 1992). The model developed by Tierney et al. focused on the likelihood of gaseous releases, and its potential effect on surrounding populations. However, it was not found to be suitable for risk assessment efforts by local jurisdiction personnel due to the level of detailed analysis required. The study conducted by Ravindra is in essence identical to the effort by the Los Angeles County Fire Department. This effort is really intended for seismic vulnerability analysis of individual facilities, and requires significant expert input,



Flowchart 11.1: Hazardous Materials Release Relationship to other Modules in the Earthquake Loss Estimation Methodology

including a walk-through inspection. Furthermore, this effort is aimed at large complexes similar to petrochemical facilities, and is not suitable for a more general application. There is, therefore, the need for a more general model that can be used by emergency preparedness officials at the local jurisdiction level so that they can determine the potential for hazardous materials incidents occurring during earthquakes.

Due to the limitations of state-of-the-art hazardous materials release models, this module is restricted to establishing a standardized approach for classifying materials and developing a good database that can be used by local planners to identify those facilities that may be most likely to have significant releases in future earthquakes. A default database of potential sites is provided from an EPA database of hazardous materials sites. This database can be supplemented by the user with local information. A more detailed vulnerability assessment would involve going to individual facilities to determine how chemicals are stored, the vulnerability of buildings and storage tanks and other relevant information.

11.1.2 Classification of Hazardous Materials

The most widely used detailed classification scheme is the one that has been developed by the National Fire Protection Association, and is presented in the 1991 Uniform Fire Code, among other documents. This classification scheme is shown in Table 11.1. The hazards posed by the various materials are divided into two major categories: Physical Hazards and Health Hazards. Depending upon the exact nature of the hazard, these two major categories are divided into subcategories. These subcategories of hazards, with their definitions, and examples of materials that fall within each category, are contained in Appendix 11A and 11B. A more detailed description of these categories, with more extensive examples can be found in Appendix VI-A of the 1991 Uniform Fire Code. Table 11.1 also contains minimum quantities of the materials that must be on site to require permitting according to the Uniform Fire Code. It should be noted that the minimum permit quantities might vary depending upon whether the chemical is stored inside or outside of a building.

11.1.3 Input Requirements and Output Information

The input to this module is essentially a listing of the locations of facilities storing hazardous materials and the types/amounts of the materials stored at the facility. Facilities need only be identified if they use, store or handle quantities of hazardous materials in excess of the quantities listed in Table 11.1. Other facilities that may have hazardous materials, but in quantities less than those listed in Table 11.1 should not be included in the database because it is anticipated that releases of these small quantities will not put significant immediate demands on health and emergency services. However, the user may choose to modify threshold amounts in building the database.

Table 11.1: Classification of Hazardous Materials and Permit Amounts

Label	Material Type	Permit Amount		Hazard Type & Remarks
		Inside Building	Outside Building	
HM01	Carcinogens	10 lbs	10 lbs	Health
HM02	Cellulose nitrate	25 lbs	25 lbs	Physical
HM03	Combustible fibers	100 cubic ft	100 cubic ft	Physical
	Combustible liquids			Physical
HM04	Class I	5 gallons	10 gallons	
HM05	Class II	25 gallons	60 gallons	
HM06	Class III-A	25 gallons	60 gallons	
HM07	Corrosive gases	Any amount	Any amount	Health [1]
HM08	Corrosive liquids	55 gallons	55 gallons	Physical; Health
	Cryogens			
HM09	Corrosive	1 gallon	1 gallon	Health
HM10	Flammable	1 gallon	60 gallons	Physical
HM11	Highly toxic	1 gallon	1 gallon	Health
HM12	Nonflammable	60 gallons	500 gallons	Physical
HM13	Oxidizer (including oxygen)	50 gallons	50 gallons	Physical
HM14	Highly toxic gases	Any amount	Any amount	Health; [1]
HM15	Highly toxic liquids & solids	Any amount	Any amount	Health
HM16	Inert	6,000 cubic ft	6,000 cubic ft	Physical; [1]
HM17	Irritant liquids	55 gallons	55 gallons	Health
HM18	Irritant solids	500 lbs	500 lbs	Health
HM19	Liquefied petroleum gases	> 125 gallons	> 125 gallons	Physical
HM20	Magnesium	10 lbs	10 lbs	Physical
HM21	Nitrate film	(Unclear)	(Unclear)	Health
HM22	Oxidizing gases (including oxygen)	500 cubic feet	500 cubic feet	Physical [1]
	Oxidizing liquids			Physical
HM23	Class 4	Any amount	Any amount	
HM24	Class 3	1 gallon	1 gallon	
HM25	Class 2	10 gallons	10 gallons	
HM26	Class 1	55 gallons	55 gallons	
	Oxidizing solids			Physical
HM27	Class 4	Any amount	Any amount	
HM28	Class 3	10 lbs	10 lbs	
HM29	Class 2	100 lbs	100 lbs	
HM30	Class 1	500 lbs	500 lbs	
	Organic peroxide liquids and solids			Physical
HM31	Class I	Any amount	Any amount	
HM32	Class II	Any amount	Any amount	
HM33	Class III	10 lbs	10 lbs	
HM34	Class IV	20 lbs	20 lbs	
	Other health hazards			Health
HM35	Liquids	55 gallons	55 gallons	
HM36	Solids	500 lbs	500 lbs	

Table 11.1: Classification of Hazardous Materials and Permit Amounts (cont.)

Label	Material Type	Permit Amount		Hazard Type & Remarks
		Inside Building	Outside Building	
HM37	Pyrophoric gases	Any amount	Any amount	Physical [1]
HM38	Pyrophoric liquids	Any amount	Any amount	Physical
HM39	Pyrophoric solids	Any amount	Any amount	Physical
HM40	Radioactive materials	1 m Curie in unsealed source	1 m Curie in sealed source	Health [1]
HM41	Sensitizer, liquids	55 gallons	55 gallons	Health
HM42	Sensitizer, solids	500 lbs	500 lbs	Health
HM43	Toxic gases	Any amount	Any amount	Health [1]
HM44	Toxic liquids	50 gallons	50 gallons	Health
HM45	Toxic solids	500 lbs	500 lbs	Health
HM46	Unstable gases (reactive)	Any amount	Any amount	Physical [1]
	Unstable liquids (reactive)			Physical
HM47	Class 4	Any amount	Any amount	
HM48	Class 3	Any amount	Any amount	
HM49	Class 2	5 gallons	5 gallons	
HM50	Class 1	10 gallons	10 gallons	
	Unstable solids (reactive)			Physical
HM51	Class 4	Any amount	Any amount	
HM52	Class 3	Any amount	Any amount	
HM53	Class 2	50 lbs	50 lbs	
HM54	Class 1	100 lbs	100 lbs	
	Water-reactive liquids			Physical
HM55	Class 3	Any amount	Any amount	
HM56	Class 2	5 gallons	5 gallons	
HM57	Class 1	10 gallons	10 gallons	
	Water-reactive solids			Physical
HM58	Class 3	Any amount	Any amount	
HM59	Class 2	50 pounds	50 pounds	
HM60	Class 1	100 pounds	100 pounds	

[1] Includes compressed gases

To build the hazardous materials database for a selected region, the user should attempt to gather the following information:

- Name of Facility or Name of Company
- Street Address
- City
- County
- State
- Zip Code
- Name of Contact in Company
- Phone Number of Contact in Company
- Standard Industrial Classification (SIC) Code
- Chemical Abstracts Service (CAS) Registry Number
- Chemical Name

- Chemical Quantity
- Hazardous Material Class (From Table 11.1)
- Latitude and Longitude of Facility

The Chemical Abstracts Service (CAS) registry number is a numeric designation assigned by the American Chemical Society's Chemical Abstracts Service and uniquely identifies a specific chemical compound. This entry allows one to conclusively identify a material regardless of the name or naming system used. To obtain this data the user must identify the local agency with which users of hazardous materials must file for permits. Based upon current understanding of the process, this local agency would be the Fire Department for incorporated areas, and the County Health Department for unincorporated areas. The user may opt to use only the information contained in a modified version of the EPA-TRI Database that is provided in the methodology. This database, however, is limited and the user is urged to collect additional inventory.

The output of this module is essentially a database that can be sorted according to any of the fields listed above. It can be displayed on a map and overlaid with other maps.

11.2 Description of Methodology

The analysis here is divided into three levels, as described below:

- Default Analysis: Listing of all facilities housing hazardous materials that are contained in the default hazardous materials database.
- User-Supplied Data Analysis: Listing of all facilities housing hazardous materials that are contained in the default hazardous materials database and refined by the user with locally available information.
- Advanced Data and Models Analysis: Detailed risk assessment for individual facilities, including expert-generated estimates.

11.3 Guidance for Expert-Generated Estimates

A detailed analysis is quite involved and is intended to provide the user with a relatively good estimate of the likelihood of a hazardous materials incident occurring at individual facilities during an earthquake. The detailed analysis therefore provides vulnerabilities of individual facilities. While the model were based primarily on location of facilities and type(s) and quantities of hazardous materials on site, a more detailed analysis is intended to take into account a number of other factors including the level of preparedness of individual facilities and the type of structure within which the hazardous materials are located. To do this detailed analysis, it is necessary to have an expert conduct a detailed analysis of individual facilities.

The level of sophistication to be attained in an analysis can vary significantly, depending upon how the analysis is defined. It is recommended very strongly that the user clearly identify the purpose and scope of the analysis first before engaging an expert to conduct the analysis. Based on the level of analysis expected, the user then has to identify and select an expert, or several experts, to conduct the analysis. In any case, it will be necessary for the expert(s) to conduct a thorough survey and inspection of the facilities. The areas that need to be covered include the following: structures, building contents including equipment, storage areas, tanks, and emergency preparedness. Depending upon the level of the analysis, the experts required could cover the following: a hazardous materials expert, a structural engineer, an emergency planner, and a mechanical engineer. The role(s) each of these experts would play is explained below.

Input Requirements

The most elementary form of detailed analysis would consist of a hazardous materials expert doing a walk through to identify target hazard areas. In most jurisdictions, the fire department personnel are the best trained in issues pertaining to hazardous materials. Many fire departments are also willing to meet with major users of hazardous materials to do what is termed "pre-planning". In this effort, fire departments visit the facilities of users, identify areas that they think are particularly vulnerable, and suggest improvements. If there were code violations, the fire department personnel would point this out. In highly industrialized areas, there are consulting firms that are capable of conducting this assessment. The smaller consulting firms tend to be comprised only of individuals with expertise in hazardous materials issues.

It must be borne in mind that when assessing the potential for hazardous materials releases during earthquakes, the performance of the structure and the performance of nonstructural items are both important. Another very important factor is the level of preparedness, especially where it pertains to the ability to contain an incident and prevent it from spreading or enlarging.

The structural and nonstructural vulnerability of a hazardous materials facility are assessed by a qualified structural engineer. For example, the integrity of an above ground storage tank, containing 100,000 gallons of petroleum, should be evaluated by a structural engineer.

A large number of hazardous materials incidents during earthquakes have occurred at locations where the structure itself suffered no damage. This has been due to the manner in which the hazardous materials are stored and used within the buildings or structures. Generally, it is the extent to which nonstructural hazard mitigation measures have been implemented that determines the vulnerability of the contents. At the present time there is no profession that specializes in "nonstructural engineering". A reference on nonstructural hazard mitigation measures has been written by Reitherman (1983). A more specific paper discussing hazard prevention techniques in the laboratory has been written by Selvaduray (1989). Though not directly pertaining to industrial facilities, FEMA has developed a guide for nonstructural hazard mitigation in hospitals (FEMA, 1989). Hazard mitigation strategies, particularly where they pertain to preventing toxic gas releases during earthquakes, have been studied by ABAG, and are contained in a special report prepared by ABAG (1991).

In conducting a detailed analysis, it is important not only to assess the potential for occurrence of incidents, but it is also important to assess the capability of containing incidents and preventing them from spreading or becoming enlarged. The level of preparedness of the individual facilities generally determines this. There have been a number of cases where the incidents would have been smaller than they actually were, had the organization/facility had the capability to respond in a timely manner. The type of expert needed here is an "Emergency Planner". Unfortunately, it is not easy to find an emergency planner who specializes in assessing individual facilities. Here again, perhaps the most qualified and educated personnel are fire department personnel. In most cases, hazardous materials consultants also address issues pertaining to response. In the case when an expert is not available, the document by the U.S. Environmental Protection Agency (EPA, 1987), which provides technical guidance for hazards analysis and emergency planning for extremely hazardous substances is an excellent guide. Another useful guide is the "Hazardous Materials Emergency Response Guide" published by the National Response Team (1987). The user should keep in mind that both of these documents are quite general in nature, and do not address earthquake concerns specifically. Nevertheless, in the absence of more specific information, these guides are definitely useful in getting the user started towards assessing the risks.

Depending upon the type of facility, there could also be a large number of mechanical systems, including piping that either utilize or carry hazardous materials. Examples of such facilities include petroleum refineries, semiconductor processing facilities, and polymer resin synthesis facilities. In such cases, the type of expert capable of conducting an adequate vulnerability analysis of the mechanical and piping systems would be a mechanical engineer. It should be pointed out that mechanical engineering is a very broad field, and the particular type of mechanical engineer who would be suitable for a task such as the one posed here would be one with a very strong background in plant safety, and preferably also in structural analysis. A number of hazardous materials releases during past earthquakes have occurred in mechanical and piping systems. This component should therefore not be ignored. A book on assessing the earthquake vulnerability of building equipment has been written by McGavin (1983). This book provides particularly valuable information on anchoring of equipment. One approach to assessing the vulnerability of hazardous materials piping systems has been developed and presented by Kircher (1990), and can potentially be utilized by mechanical engineers having the capability to conduct particularly sophisticated analysis.

There are two documents that provide a general methodology for assessing the earthquake vulnerability of entire facilities, particularly those that contain hazardous materials. One such document is the "Proposed Guidance for RMPP Seismic Assessments" contained within the Los Angeles County Fire Department's Risk Management and Prevention Program Guidelines. This document provides guidelines for assessing the earthquake vulnerability of facilities that use hazardous materials, especially Acutely Hazardous

Materials (AHM). However, the methodology provided does require a structural engineer. On the positive side, there are relatively detailed guidelines for assessing the vulnerability of piping systems. Ravindra (1992) has presented an approach, that is very similar to the one developed by the Los Angeles County Fire Department, for seismic evaluation of hazardous materials facilities.

Output Information

Ideally, upon completion of a detailed analysis, the user will have a very good idea of the vulnerability (ies) contained within each facility. The user will have a relatively good grasp of the potential for occurrence of hazardous materials releases, during earthquakes, at each of the facilities analyzed. While this might not be a quantified probability number, the results of the analysis should provide sufficient information to categorize the likelihood in terms of “high, medium, or low”. In addition to the overall likelihood, the user should also be able to identify the locations within each facility where hazardous materials releases might occur. This can be particularly important for larger facilities that cover several acres. It is only by identifying specific locations within the larger facilities that adequate response can be planned for. Another piece of information that the user should obtain from an expert-assisted analysis is the likely consequence of a hazardous materials release. Particularly important here is the scope of the release, and the manner in which it would affect the surrounding area. It is expected that this can be determined by combining the analysis data with other data such as hazard, type of the material, phase of the material (solid, liquid or gas), prevailing weather conditions, and demographics of the surrounding region.

The analysis should also provide the user with the ability to assess the response capability of each facility inspected. Depending upon the response capability that each facility has, the user would need to adjust his/her response capability to account for this. In general, the larger industrial facilities, such as petroleum refineries, tend to have relatively extensive response capability in-house. As such, they would be able to be the “first responders”, with the local jurisdictions providing the necessary backup capabilities. On the other hand, if the larger industrial facilities do not have sufficient capabilities to respond to hazardous materials releases, the analysis would provide the local emergency preparedness officials with the opportunity to require such facilities to increase their response capability.

11.4 References

Association of Bay Area Governments 1991, “Toxic Gas Releases in Earthquakes: Existing Programs, Sources, and Mitigation Strategies,” November.

Federal Emergency Management Agency 1989, “Non Structural Earthquake Hazard Mitigation for Hospitals and other Health Care Facilities”, FEMA IG 370, May.

International Conference of Building Officials, *Uniform Fire Code*, 1991.

Kircher, C. A. & Lashkari, B., 1990, "Seismic Restraint of Hazardous-Materials Piping," *ATC-29 Seminar: Seismic Design and Performance of Equipment and Nonstructural Elements in Buildings and Industrial Structures*, Applied Technology Council, Irvine, California, October.

Kircher, C. A., et al., 1987, "Seismic Restraint of Hazardous Piping Systems in Industrial Buildings (Phase I)," Jack R. Benjamin Associates, Mt. View, California, April.

Los Angeles County Fire Department 1992, Hazardous Materials Division, "Risk Management and Prevention Program Guidelines", July.

McGavin, A., 1983, *Protection of Essential Building Equipment*, McGraw-Hill.

National Response Team 1987, *Hazardous Materials Emergency Planning Guide*, March.

Ravindra, M., 1992. Seismic Assessment of Chemical Facilities under California Risk Management and Prevention Program, *Proceedings International Conference on Hazard Identification and Risk Analysis, Human Factors and Human Reliability in Process Safety*, Orlando, Florida, Proceedings published by Center for Chemical Process Safety, American Institute of Chemical Engineers, January, 1992.

Reitherman, R. K., 1982, "Earthquake-Caused Hazardous Material Releases", *1982 Hazardous Material Spills Conference Proceedings*, April, 1982.

Reitherman, R., 1983, "Reducing the Risks of Nonstructural Earthquake Damage: A Practical Guide", Scientific Service, Inc., Redwood City, Feb 1983.

Selvaduray, G., Wyatt, E. & Perkins, J., 1993, Analysis of Hazardous Materials Releases during the Loma Prieta Earthquake, *Proceedings 3rd US-Japan Workshop Urban Earthquake Hazard Reduction*, EERI Publication No. 93-B, February 1993

Selvaduray, G., 1989, "Earthquake Hazard Reduction in the Laboratory", *Proc. HAZMACON 89, Association of Bay Area Governments*, April.

Tierney, K. J., Seligson, H. A. & Eguchi, R. T., 1990, "Chemical Hazards, Mitigation, and Preparedness in Areas of High Seismic Risk: A Methodology for Estimating the Risk of Post-Earthquake Hazardous Materials Releases", A Report prepared for The National Science Foundation and The National Center for Earthquake Engineering Research. January 8.

U.S. Environmental Protection Agency 1987, FEMA, U.S. Department of Transportation, *Technical Guidance for Hazards Analysis - Emergency Planning for Extremely Hazardous Substances*, U.S. Environmental Protection Agency December.

Appendix 11A
Listing of Chemicals contained in SARA Title III, including their CAS Numbers, Hazards and Treshold Planning Quantities

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00075-86-5	Acetone cyanohydrin	Poison	1,000
01752-30-3	Acetone thiosemicarbazide	Poison	1,000 +
00107-02-8	Acrolein	Flammable liquid & poison	500
00079-06-1	Acrylamide	Poison	1,000 +
00107-13-1	Acrylonitrile	Flammable liquid & poison	10,000
00814-68-6	Acrylyl chloride	Poison	100
00111-69-3	Adiponitrile	Poison	1,000
00116-06-3	Aldicarb	Deadly poison	100 +
00309-00-2	Aldrin	Poison	500 +
00107-18-6	Allyl alcohol1	Flammable liquid & poison	1,000
00107-11-9	Allylamine	Flammable liquid & poison	500
20859-73-8	Aluminum phosphide	Flammable solid & poison	500
00054-62-6	Aminopterin	Poison	500 +
00078-53-5	Amiton	Deadly poison	500
03734-97-2	Amiton oxalate	Deadly poison	100 +
07664-41-7	Ammonia, anhydrous	Poison	500
00300-62-9	Amphetamine	Deadly poison	1,000
00062-53-3	Aniline	Poison	1,000
00088-05-1	Aniline, 2,4,6-trimethyl	Poison	500
07783-70-2	Antimony pentafluoride	Corrosive to skin, eyes, mucuous membranes	500
01397-94-0	Antimycin A	Poison	1,000 +
00086-88-4	Antu	Poison	500 +
01303-28-2	Arsenic pentoxide	Poison	100 +
01327-53-3	Arsenous oxide	Poison	100
07784-34-1	Arsenous trichloride	Poison	500
07784-42-1	Arsine	Poison gas & flammable gas	100
02642-71-9	Azinphos-ethyl	Poison	100 +
00086-50-0	Azinphos-methyl	Poison	10 +
00098-87-3	Benzal chloride	Moderately toxic	500
00098-16-8	Benzehamine,3-(trifluoromethyl)-	Poison	500
00100-14-1	Benzene, 1-(chloromethyl)-4-nitro-	Poison	500 +
00098-05-5	Benzenearsonic acid	Deadly poison	10 +
03615-21-2	Benzimidazole, 4,5-dichloro-2-(trifluoromethyl)	Poison	500 +
00098-07-7	Benzotrichloride (benzoic trichloride)	Corrosive & poison	100
00100-44-7	Benzyl chloride	Corrosive & poison	500
00140-29-4	Benzyl cynaide	Poison	500
15271-41-7	Bicyclo [2,2,1]heptane-2-carbonitrile,5-chloro-6((((methylamino)carbonyl)oxy)imino)-(1S-(1-alpha,2-beta,4-alpha,5-alpha,6E))-	Poison	500 +
00111-44-4	Bis(2chloroethyl)ether	Poison	10,000
00542-88-1	Bis(chloromethyl)ether	Poison & carcinogen	100
00534-07-6	Bis(chloromethyl)ketone	Poison	10 +
04044-65-9	Bitoscanate	Poison	500 +
10294-34-5	Boron trichloride	Corrosive, poison, irritant & reactive with water	500
07637-07-2	Boron trifluoride	Poison & strong irritant	500
00353-42-4	Borontrifluoride compound with methyl ether (1:1)	Flammable, corrosive & poison	1,000
28772-56-7	Bromadiolone	Deadly poison	100 +
07726-95-6	Bromine	Corrosive & poison	500
01306-19-0	Cadmium oxide	Poison	100 +
02223-93-0	Cadmium stearate	Poison	1,000 +
07778-44-1	Calcium arsenate	Poison & carcinogen	500 +
00056-25-7	Cantharidin	Deadly poison	100 +
00051-83-2	Carbachol chloride	Deadly poison	500 +

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
26419-73-8	Carbamic acid, methyl-O-(((2,4-dimethyl-1,3-dithiolan-2-yl)methylene)amino)-	Poison	100 +
01563-66-2	Carbofuran	Poison	10 +
00075-15-0	Carbon disulfide	Flammable liquid & poison	10,000
000786-19-6	Carbophenothion	Poison	500
00057-74-9	Chlordane	Flammable liquid & poison	1,000
00470-90-6	Chlorfenvinfos	Poison	500
07782-50-5	Chlorine (not muratic acid or bleach)	Poison gas	100
24934-91-6	Chlormephos	Poison	500
00999-81-5	Chlormequat chloride		100 +
00079-11-8	Chloroacetic acid	Corrosive & poison	100 +
00107-07-3	Chloroethanol	Flammable liquid & poison	500
00627-11-2	Chloroethyl chloroformate	Poison	1,000
00555-77-1	Tris(2-chloroethyl)amine	Moderately toxic	100
00067-66-3	Chloroform	Poison	10,000
00107-30-2	Chloromethyl methyl ether	Flammable liquid & poison	100
03691-35-8	Chlorophacinone	Poison	100 +
01982-47-4	Chloroxuron	Poison	500 +
21923-23-9	Chlorthiophos	Poison	500
10025-73-7	Chromic chloride	Poison	1 +
10210-68-1	Cobalt carbonyl	Poison	10 +
62207-76-5	Cobalt,((2,2'-(1,2-ethanediylbis(nitrilomethylidyne))bis(6-fluorophenolato))(2-)-N,N',O,O')-	Poison	100+
00064-86-6	Colchicine	Poison	10 +
00056-72-4	Coumaphos	Poison	100 +
05836-29-3	Coumatetralyl	Poison	500 +
00095-48-7	Othro-cresol	Poison	1,000 +
00535-89-7	Crimidine	Deadly poison	100 +
00123-73-9	Crotonaldehyde	Poison	1,000
04170-30-3	E-crotonaldehyde	Flammable liquid & poison	1,000
00506-68-3	Cyanogen bromide	Poison	500 +
00506-78-5	Cyanogen iodide	Poison	1,000 +
02636-26-2	Cyanophos	Poison	1,000
00675-14-9	Cyanuric fluoride	Poison	1000
00066-81-9	Cycloheximide	Poison	100 +
000108-91-8	Cyclohexylamine	Flammable liquid & poison	10,000
17702-41-9	Decaborane (14)		500 +
08065-48-3	Demeton	Deadly poison	500
00919-86-8	Demeton-s-methyl	Poison	500
10311-84-9	Dialifor	Poison	100 +
19287-45-7	Diborane	Flammable gas & poison	100
00110-57-6	Trans-1,4-dichlorobutene	Poison	500
00149-74-6	Dichloromethylphenylsilane	Flammable liquid & poison	1,000
00062-73-7	Dichlorvos	Poison	1,000
00141-66-2	Dicrotophos	Poison	100
01464-53-5	Diepoxybutane	Poison	500
00814-49-3	Diethyl chlorophosphate	Deadly poison	500
01642-54-2	Diethylcarbamazine citrate	Poison	100+
00071-63-6	Digitoxin	Deadly poison	100+
02238-07-5	Diglycidyl ether	Poison	1,000
20830-75-5	Digoxin	Deadly poison	10+
00115-26-4	Dimefox	Poison	500
00060-51-5	Dimethiate	Poison	500+
06923-22-4	3-(Dimethoxy phosphinyloxy)-N-methyl-cis croton-amide(monocrotophos)	Poison	10
00075-78-5	Dimethyldichlorosilane	Poison & irritant	500
00057-14-7	Dimethylhydrazine	Flammable liquid & poison	1,000
00099-98-9	Dimethyl-p-phenylenediamine	Poison	10+
02524-03-0	Dimethyl phosphochloridothioate	Corrosive & poison	500
00077-78-1	Dimethyl sulfate	Corrosive & poison	500
00644-64-4	Dimetilan	Poison	500+
00534-52-1	4,6-Dinitro-o-cresol	Poison	10+

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00088-85-7	Dinoseb	Poison	100+
01420-07-1	Dinoterb	Poison	500+
00078-34-2	Dioxathion	Poison	500
00082-66-6	Diphacinone	Poison	10+
00152-16-9	Diphosphoramide, octamethyl	Poison	100
00298-04-4	Disulfoton	Poison	500
00514-73-8	Dithiazamine iodide	Poison	500+
00541-53-7	Dithiobiuret	Poison	100+
00316-42-7	Emetine, dihydrochloride	Poison	1+
00115-29-7	Endosulfan	Poison	10+
02778-04-3	Endothion	Poison	500+
00072-20-8	Endrin	Poison	500+
00106-89-8	Epichlorohydrin	Flammable liquid & poison	1,000
02104-64-5	EPN	Poison	100+
00050-14-6	Ergocalciferol	Poison	1,000+
00379-79-3	Ergotamine tartate	Poison	500+
01622-32-8	Ethanesulfonyl chloride,2-chloro	Poison	500
10140-87-1	Ethanol,1,2-dichloroacetate	Combustible & poison	1,000
00563-12-2	Ethion	Poison	1,000
13194-48-4	Ethoprophos	Poison	1,000
00538-07-8	Ethylbis(2-chloroethyl)amine	Deadly poison	500
00107-15-3	Ethylenediamine	Corrosive, flammable liquid, irritant	10,000
00371-62-0	Ethylene fluorohydrin	Poison	10
00151-56-4	Ethyleneimine	Flammable liquid & poison	500
00075-21-8	Ethylene oxide	Flammable gas & poison	1,000
00542-90-5	Ethylthiocyanate	Poison	10,000
22224-92-6	Fenamiphos	Poison	10+
00122-14-5	Fenitrothion	Poison	500
00115-90-2	Fensulfothion	Poison	500
04301-50-2	Fluenetil	Poison	100+
07782-41-4	Fluorine	Oxidizer & poison	500
00640-19-7	Fluoroacetamide (1061)	Poison	100+
00144-49-0	Fluoroacetic acid	Poison	10+
00359-06-8	Fluoroacetyl chloride	Poison	10
00051-21-8	Fluorouracil	Poison	500+
00944-22-9	Fonofos	Poison	500
00050-00-0	Formaldehyde	Combustible liquid & poison	500
00107-16-4	Formaldehyde cyanohydrin	Poison	1,000
23422-53-9	Formetanate hydrochloride	Poison	500+
02540-82-1	Formothion	Poison	100
17702-57-7	Formparanate	Poison	100+
21548-32-3	Fosthientan	Poison	500
03878-19-1	Fuberidazole	Poison	100+
00110-00-9	Furan	Flammable liquid & poison	500
13450-90-3	Gallium trichloride	Poison	500+
00077-47-4	Hexachlorocyclopentadiene	Corrosive & deadly poison	100
04835-11-4	Hexamethylenediamine,N,N-dibutyl	Poison	500
00302-01-2	Hydrazine	Flammable liquid, corrosive & poison	1,000
00074-90-8	Hydrocyanic acid	Deadly poison	100
07647-01-0	Hydrogen chloride (gas only)	Highly corrosive irritant	500
07664-39-3	Hydrogen fluoride	Corrosive & poison	100
07722-84-1	Hydrogen peroxide (conc. >52%)	Oxidizer, moderately toxic	1,000
07783-07-5	Hydrogen selenide	Flammable gas & deadly poison	10
07783-06-4	Hydrogen sulfide	Flammable gas & poison	500
00123-31-9	Hydroquinone	Poison	500+
13463-40-6	Iron pentacarbonyl	Poison	100
00297-78-9	Isobenzan	Poison	100+
00078-82-0	Isobutyronitrile	Flammable liquid & poison	1,000
00102-36-3	Isocyanic aicd,3,4-dichlorophenyl ester	Poison	500+
00465-73-6	Isodrin	Poison	100+

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00055-91-4	Isofluorphate	Poison	100
04098-71-9	Isophorone diisocyanate	Poison	100
00108-23-6	Isopropyl chloroformate	Flammable liquid & poison	1,000
00119-38-0	Isopropylmethylpyrazolyl dimethylcarbamate	Poison	500
00078-97-7	Lactonitrile	Poison	1,000
21609-90-5	Leptophos	Poison	500+
00541-25-3	Lewisite	Poison	10
00058-89-9	Lindane	Poison	1,000+
07580-67-8	Lithium hydride	Flammable solid & poison	100
00109-77-3	Malononitrile	Poison	500+
12108-13-3	Mangenese tricarbonyl methylcyclopentadienyl	Poison	100
00950-10-7	Mephosfolan	Poison	500
01600-27-7	Mercuric acetate	Poison	500+
07487-94-7	Mercuric chloride	Poison	500+
21908-53-2	Mercuric oxide	Powerful oxidant	500+
10476-95-6	Methacrolein diacetate	Poison	1,000
00760-93-0	Methacrylic anhydride	Poison	500
00126-98-7	Methylacrylonitrile	Poison	500
00920-46-7	Methacryloyl chloride	Poison	100
30674-80-7	Methacryloyloxyethylisocyanate	Poison	100
10265-92-6	Methamidophos	Poison	100+
00558-25-8	Methanesulfonyl fluoride	Poison	1,000
00950-37-8	Methidathion	Poison	500+
02032-65-7	Methiocarb	Poison	500+
16752-77-5	Methomyl	Poison	500+
00151-38-2	Methoxyethylmercuric acetate	Poison	500+
00074-83-9	Methyl bromide	Poison gas	1,000
00080-63-7	Methyl 2-chloroacrylate	Moderately toxic	500
00079-22-1	Methyl chloroformate	Flammable liquid, corrosive & poison	500
00060-34-4	Methyl hydrazine	Flammable liquid, corrosive, poison	500
00624-83-9	Methyl isocyanate	Flammable liquid & poison	500
00556-61-6	Methyl isothiocyanate	Flammable liquid & poison	500
00074-93-1	Methyl mercaptan	Flammable gas & poison	500
00502-39-6	Methylmercuric dicyanamide	Poison	500+
03735-23-7	Methyl phenkapton	Poison	500
00676-97-1	Methyl phosphonic dichloride	Corrosive & poison	100
00556-64-9	Methyl thiocyanate	Poison	10,000
00075-79-6	Methyl trichlorosilane	Flammable liquid, corrosive & poison	500
00079-84-4	Methyl vinyl ketone		10
01129-41-5	Metolcarb	Poison	100+
07786-34-7	Mevinphos	Poison	500
00315-18-4	Mexacarbate	Poison	500+
00050-07-7	Mitomycin C	Poison	500+
06923-22-4	Monocrotophos	Poison	10+
02763-96-4	Muscinol	Poison	10,000
00505-60-2	Mustard gas	Poison	500
13463-39-3	Nickel carbonyl	Flammable liquid & poison	1
00054-11-5	Nicotine	Poison	100
00065-30-5	Nicotine sulfate	Poison	100+
07697-37-2	Nitric acid (.40% pure)	Corrosive, oxidizer & poison	1,000
10102-43-9	Nitric oxide	Poison gas	100
00098-95-3	Nitrobenzene	Poison	10,000
01122-60-7	Nitrocyclohexane	Poison	500
10102-44-0	Nitrogen dioxide	Oxidizer & moderately toxic	100
00051-75-2	Nitrogen mostard	Deadly poison	10
00062-75-9	N-Nitrosodimethylamine	Poison	1,000
00991-42-4	Norbormide	Poison	100+
PMN-82-147	Organorhodium complex	Flammable & toxic	10+
00630-60-4	Ouabain	Poison	100+
23135-22-0	Oxamyl	Poison	100+

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00078-71-7	Oxetane,3,3,-bis(chloromethyl)-	Poison	500
02497-07-6	Oxydisulfoton	Poison	500
10028-15-6	Ozone	Poison	100
01910-42-5	Paraquat	Poison	10+
02074-50-2	Paraquat methosulfate	Poison	10+
00056-38-2	Parathion	Poison	100
00298-00-0	Parathion-methyl	Poison	100+
13002-03-8	Paris green	Poison	500+
19624-22-7	Pentaborane	Flammable liquid & poison	500
02570-26-5	Pentadecylamine	Poison	100+
00079-21-0	Peracetic acid	Corrosive & poison	500
00594-42-3	Perchloromethylmercaptan	Poison	500
00108-95-2	Phenol	Poison	500+
04418-66-0	Phenol,2,2-thiobis(4-chloro-6-methyl)	Poison	100+
00064-00-6	Phenol,3-(1-methylethyl)-methylcarbamate	Poison	500+
00058-36-6	Phenoarsazine 10,10-oxydi-	Poison	500+
00696-28-6	Phenyl dichloroarsine	Poison	500
00059-88-1	Phenylhydrazine hydrochloride	Poison	1,000+
00062-38-4	Phenylmercury acetate	Poison	500+
02097-19-0	Phenylsilatrane	Poison	100+
00103-85-5	Phenylthiourea	Poison	100+
00298-02-2	Phorate	Poison	10
04104-14-7	Phosacetim	Poison	100+
00947-02-4	Phosfolan	Poison	100+
00075-44-5	Phosgene	Poison gas	10
00732-11-6	Phosmet	Poison	10+
13171-21-6	Phosphamidon	Poison	100
07803-51-2	Phosphine	Flammable & poison gas	500
02665-30-7	Phosphonothioic acid, methyl-o-(4-nitrophenol)o-phenyl ester	Poison	500
50782-69-9	Phosphonothioic acid, methyl-s-(2-(bis(1-methylethyl)amino)o-ethyl ester`	Poison	100
02703-13-1	Phosphonothioic acid methyl,-o-ethyl-o-4-(methylthio)phenyl ester	Deadly poison	500
03254-63-5	Phosphoric acid, dimethyl,4-(mehtylthio)phenyl ester	Poison	500
02587-90-8	Phosphorothioic aicd,o,o-dimethyl-s-(2-methyl-thio-ethyl ester	Poison	500
07723-14-0	Phosphorus	Flammable solid & poison	100
10025-87-3	Phosphorus oxychloride	Corrosive, irritant & poison	500
10026-13-8	Phosphorus pentachloride	Corrosive & poison	500
01314-56-3	Phosphorus pentoxide	Corrosive & poison	10
07719-12-2	Phosphorus trichloride	Corrosive & poison	1,000
00057-47-6	Physostigmine	Poison	100+
00057-64-7	Physostigmine, salicylate (1:1)	Poison	100+
00124-87-8	Picrotoxin	Poison	500+
00110-89-4	Piperidine	Poison	1,000
23505-41-1	Pirimifos-ethyl	Poison	1,000
10124-50-2	Potassium arsenite	Poison	500+
00151-50-8	Potassium cyanide	Deadly poison	100
00506-61-6	Potassium silver cyanide	Poison & irritant	500
02631-37-0	Promecarb	Poison	500+
00106-96-7	Propagyl bromide	Flammable liquid & deadly poison	10
00057-57-8	beta-Propiolactone	Poison	500
00107-12-0	Propionitrile	Flammable liquid & poison	500
00542-76-7	Propionitrile, 3-chloro	Poison	1,000
00070-69-9	Propiophenone,4-amino	Poison	100+
00109-61-5	Propyl chloroformate	Flammable liquid, corrosive & poison	500
00075-56-9	Propylene oxide	Flammable liquid & poison	10,000
00075-55-8	Propyleneimene	Flammable liquid & poison	10,000
02275-18-5	Prothoate	Poison	100+
00129-00-0	Pyrene	Poison	1,000+

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00140-76-1	Pyridine,2-methyl-5-vinyl	Poison	500
00504-24-5	Pyridine,4-amino	Poison	500+
01124-33-0	Pyridine,4-nitro-,1-oxide	Poison	500+
53558-25-1	Pyriminil	Poison	100+
14167-18-1	Salcomine	Poison	500+
00107-44-8	Sarin	Deadly poison	10
07783-00-8	Selenous acid	Poison	1,000+
07791-23-3	Selenium oxychloride	Poison	500
00563-41-7	Semicarbazide hydrochloride	Poison	1,000+
03037-72-7	Silane, (4-aminobutyl)diethoxymethyl	Poison	1,000
07631-89-2	Sodium arsenate	Poison	1,000+
07784-46-5	Sodium arsenite	Deadly poison	500+
26628-22-8	Sodium azide	Poison	500
00124-65-2	Sodium cacodylate	Poison	100+
00143-33-9	Sodium cyanide	Deadly poison	100
00062-74-8	Sodium fluoroacetate	Deadly poison	10+
13410-01-0	Sodium selenate	Poison	100+
10102-18-8	Sodium selenite	Poison	100+
10102-20-2	Sodium tellurite	Poison	500+
00900-95-8	Stannane, acetoxytriphenyl	Poison	500+
00057-24-9	Strychnine	Poison	100+
00060-41-3	Strychnine, sulfate	Poison	100+
03689-24-5	Sulfotep	Poison	500
03569-57-1	Sulfoxide,3-chloropropyloctyl	Poison	500
07446-09-5	Sulfur dioxide	Poison gas	500
07783-60-0	Sulfur tetrafluoride	Poison gas	100
07446-11-9	Sulfur trioxide	Corrosive & poison	100
07664-93-9	Sulfuric acid (>93%)	Corrosive & poison	1,000
00077-81-6	Tabun	Poison	10
13494-80-9	Tellurium	Poison	500+
07783-80-4	Tellarium hexafluoride	Poison gas	100
00107-49-3	TEPP	Poison	100
13071-79-9	Terbufos	Deadly poison	100
00078-00-2	Teraethyllead	Flammable liquid & poison	100
00597-64-8	Tetraethyltin	Poison	100
00075-74-1	Tetramethyllead	Poison	100
00509-14-8	Tetranitromethane	Oxidizer & poison	500
10031-59-1	Thallium sulfate	Poison	100+
06533-73-9	Thallous carbonate	Poison	100+
07791-12-0	Thallous chloride	Poison	100+
02757-18-8	Thallous malonate	Poison	100+
07446-18-6	Thallous sulfate	Poison	100+
02231-57-4	Thiocarbazide	Poison	1,000+
39196-18-4	Thiofanox	Poison	100+
00297-97-2	Thioazin	Poison	500
00108-98-5	Thiophenol	Flammable liquid & poison	500
00079-19-6	Thiosemicarbazide	Poison	100+
05344-82-1	Thiourea, (2-chlorophenyl)	Poison	100+
00614-78-8	Thiourea (2-methylphenyl)	Poison	500+
07550-45-0	Titanium tetrachloride	Corrosive & poison	100
00584-84-9	Toluene 2,4-diisocyanate	Poison	500
00091-08-7	Toluene 2,6-diisocyanate	Poison	100
08001-35-2	Toxaphene	Poison	500+
01031-47-6	Triamiphos	Poison	500+
24017-47-8	Triazofos	Poison	500
00076-02-8	Trichloroacetyl chloride	Corrosive & moderately toxic	500
01558-25-4	Trichloro(chloromethyl)silane	Poison	100
27137-85-5	Trichloro(chlorophenyl)silane	Corrosive & poison	500
00115-21-9	Trichloroethylsilane	Flammable liquid & poison	500
00327-98-0	Trichloronate	Poison	500
00098-13-5	Trichlorophenylsilane	Corrosive & poison	500
00998-30-1	Triethoxysilane	Poison	500

CAS Number	Chemical Name	Hazard	Treshold Planning Quantity (pounds)
00075-77-4	Trimethylchlorosilane	Flammable liquid, corrosive & moderately toxic	1,000
00824-11-3	Trimethylolpropane phosphate	Poison	100+
01066-45-1	Trimethyltin chloride	Deadly poison	500+
00639-58-7	Triphenyltin chloride	Poison	500+
02001-95-8	Valinomycin	Poison	1,000+
01314-62-1	Vanadium pentoxide	Poison	100+
00108-05-4	Vinyl acetate monomer	Flammable liquid & moderately toxic	1,000
00081-81-2	Warfarin	Poison	500+
00129-06-6	Warfarin sodium	Poison	100+
28347-13-9	Xylene dichloride	Poison	100+
58270-08-9	Zinc, dichloro(4,4-dimethyl-5((((methylamino)carbonyl)oxino)pentanenitrile)-,(T-4)	Poison	100+
01314-84-7	Zinc phosphide	Flammable solid & poison	500

Note: For the Treshold Planning Quantities marked with a "+", the quantity listed applies only if in powdered form and with a particle size of less than 100 microns, or is handled in solution or molten form, or has a NFPA rating for reactivity of 2, 3 or 4. Otherwise the Treshold Planning Quantity is 10,000 lbs. The material is still required to be reported on an annual inventory at the Treshold Planning Quantity or 500 lbs, whichever is less.

Source of hazard information: N. Irving San and Richard J. Lews, Sr., Dangerous Properties of Industrial Materials, Seventh Edition, Volumes I - III, Van Nostrand Reinhold, New York, (1989).

Appendix 11B
Listing of Chemicals contained in the TRI Database, including their CAS Numbers and Hazards

CAS NUMBER	CHEMICAL NAME	HAZARDS
75-07-0	Acetaldehyde	Poison
60-35-5	Acetamide	Experimental carcinogen
67-64-1	Acetone	Moderately toxic
75-05-8	Acetonitrile	Poison
53-96-3	2-Acetylaminofluorene	Moderately toxic
107-02-8	Acrolein	Poison
79-06-1	Acrylamide	Poison
79-10-7	Acrylic acid	Poison
107-13-1	Acrylonitrile	Poison
309-00-2	Aldrin	Poison
107-05-1	Allyl chloride	Poison
7429-90-5	Aluminum (fume or dust)	Not considered a industrial poison
1344-28-1	Aluminum oxide	Experimental tumorigen
117-79-3	2-Aminoanthraquinone	Experimental carcinogen
60-09-3	4-Aminoazobenzene	Poison
92-67-1	4-Aminobiphenyl	Poison
82-28-0	1-Amino-2-methylanthraquinone	Experimental neoplastigen
7664-41-7	Ammonia	Poison
6484-52-2	Ammonium nitrate (solution)	Powerful oxidizer & an allergen
7783-20-2	Ammonium sulfate (solution)	Moderately toxic
62-53-3	Aniline	Poison
90-04-0	o-Anisidine	Moderately toxic
109-94-9	p-Anisidine	Moderately toxic
134-29-2	o-Anisidine hydrochloride	Experimental carcinogen
120-12-7	Anthracene	Experimental tumorigen
7440-36-0	Antimony	Poison
7440-38-2	Arsenic	Carcinogen
1332-21-4	Asbestos (friable)	Carcinogen
7440-39-3	Barium	Poison
98-87-3	Benzal chloride	Poison
55-21-0	Benzamide	Moderately toxic
71-43-2	Benzene	Poison
92-87-5	Benzidine	Poison
98-07-7	Benzoic trichloride (Benzotrichloride)	Poison
98-88-4	Benzoyl chloride	Carcinogen
94-36-0	Benzoyl peroxide	Poison
100-44-7	Benzyl chloride	Poison
7440-41-7	Beryllium	Deadly poison
92-52-4	Biphenyl	Poison
111-44-4	Bis(2-chloroethyl) ether	Poison
542-88-1	Bis(chloromethyl) ether	Poison
108-60-1	Bis(2-chloro-1-methyulethyl) ether	Poison
103-23-1	Bis(2-ethylhexyl) adipate	Experimental carcinogen
75-25-2	Bromoform (Tribromomethane)	Poison
74-83-9	Bromomethane (methyl bromide)	Poison
106-99-0	1,3-Butadiene	Experimental carcinogen
141-32-2	Butyl acrylate	Moderately toxic
71-36-3	n-Butyl alcohol	Poison
78-92-2	sec-Butyl alcohol	Poison
75-65-0	tert-Butyl alcohol	Moderately toxic
85-68-7	Butyl benzyl phthalate	Moderately toxic
106-88-7	1,2-Butylene oxide	Moderately toxic
123-72-8	Butyraldehyde	Moderately toxic
2650-18-2	C.I. Acid Blue 9, diammonium salt	Poison
3844-45-9	C.I. Acid Blue, disodium salt	Experimental neoplastigen
4680-78-8	C.I. Acid Green 3	Experimental tumorigen
569-64-2	C.I. Basic Green 4	Poison
989-38-8	C.I. Basic Red 1	Poison
1937-37-7	C.I. Direct black 38	Experimental tumorigen
2602-46-2	C.I. Direct Blue 6	Experimental carcinogen

CAS NUMBER	CHEMICAL NAME	HAZARDS
16071-86-6	C.I. Direct Brown 95	Experimental carcinogen
2832-40-8	C.I. Disperse Yellow 3	Experimental tumorigen
3761-53-3	C.I. Food Red 5	
81-88-9	C.I. Food Red 15	Poison
3118-97-6	C.I. Solvent Orange 7	Experimental carcinogen
97-56-3	C.I. Solvent Yellow 3	Experimental carcinogen
842-07-9	C.I. Solvent Yellow 14	Experimental carcinogen
492-80-8	C.I. Solvent Yellow 34 (Auramine)	Poison
128-66-5	C.I. Vat Yellow 4	Experimental carcinogen
7440-43-9	Cadmiun	Poison
156-62-7	Calcium cyanamide	Poison
133-06-2	Captan	Moderately toxic
63-25-2	Carbaryl	Poison
75-15-0	Carbon disulfide	Poison
56-23-5	Carbon tetrachloride	Poison
463-58-1	Carbonyl sulfide	Poison
120-80-9	Catechol	Moderately toxic
133-90-4	Chloramben	Experimental carcinogen
57-74-9	Chlordane	Poison
7782-50-5	Chlorine	Moderately toxic
10049-04-4	Chlorine dioxide	Moderately toxic
79-11-8	Chloroacetic acid	Poison
532-27-4	2-Chloroacetophenone	Poison
108-90-7	Chlorobenzene	Poison
510-15-6	Chlorobenzilate	Experimental carcinogen
75-00-3	Chloroethane	Mildly toxic
67-66-3	Chloroform	Poison
74-87-3	Chloromethane (Methyl chloride)	Mildly toxic
107-30-2	Chloromethyl methyl ether	Poison
126-99-8	Chloroprene	Poison
1897-45-6	Chlorothalonil	Moderately toxic
7740-47-3	Chromium	Poison
7440-48-4	Cobalt	Poison
7440-50-8	Copper	Experimental tumorigen
120-71-8	p-Cresidine	Moderately toxic
1319-77-3	Cresol (mixed isomers)	Moderately toxic
108-39-4	m-Cresol	Poison
95-48-7	o-Cresol	Poison
106-44-5	p-Cresol	Poison
98-82-8	Cumene	Moderately toxic
80-15-9	Cumene hydroperoxide	Moderately toxic
135-20-6	Cupferron	Poison
110-82-7	Cyclohexane	Poison
94-75-7	2,4-D (Acetic acid,(2,4-dichlore-phenoxy))	Poison
1163-19-5	Decabromodiphenyl oxide	Experimental neoplastigen
2303-16-4	Diallate	Poison
615-05-4	2,4-Diaminoanisole	Poison
39156-41-7	2,4-Diaminoanisole sulfate	Poison
101-80-4	4,4-Diaminophenyl ether	Poison
25376-45-8	Diaminotoluane (mixed isomers)	Poison
95-80-7	2,4-Diaminotoluene	Poison
334-80-3	Diazomethane	Experimental tumorigen
132-64-9	Dibenzofuran	
96-12-8	1,2-Dibromo-3-chloropropane (DBCP)	Poison
106-93-4	1,2-Dibromoethane (Ethylene dibromide)	Poison
84-74-2	Dibutyl phthalate	Moderately toxic
25321-22-6	Dichlorobenzene (mixed isomers)	Poison
95-50-1	1,2-Dichlorobenzene	Poison
541-73-1	1,3-Dichlorobenzene	Poison
106-46-7	1,4-Dichlorobenzene	Poison
91-94-1	3,3-Dichlorobenzidine	Experimental carcinogen
75-27-4	Dichlorobromomethane	Moderately toxic
107-06-2	1,2-Dichloroethane	Poison

CAS NUMBER	CHEMICAL NAME	HAZARDS
540-59-0	1,2-Dichloroethylene	Poison
75-09-2	Dichloromethane (Methylene chloride)	Poison
120-83-2	2,4-Dichlorophenol	Poison
78-87-5	1,2-Dichloropropane	Moderately toxic
542-75-6	1,3-Dichloropropylene	Poison
62-73-7	Dichlorvos	Poison
115-32-2	Dicofol	Poison
1464-53-5	Diepoxybutane	Poison
111-42-2	Diethanolamine	Moderately toxic
117-81-7	di-(2-ethylhexyl) phthalate (DEHP)	Poison
84-66-2	Diethyl phthalate	Poison
64-67-5	Diethyl sulfate	Poison
119-90-4	3,3-Dimethoxybenzidine	Moderately toxic
60-11-7	4-Dimethylaminoazobenzene	Poison
119-93-7	3,3-Dimethylbenzidine (o-Tolidine)	Poison
79-44-7	Dimethylcarbamyl chloride	Poison
57-14-7	1,1-Dimethyl hydrazine	Poison
105-67-9	2,4-Dimethylphenol	Poison
131-11-3	Dimethyl phthalate	Moderately toxic
77-78-1	Dimethyl sulfate	Poison
534-52-1	4,6-Dinitro-o-cresol	Poison
51-28-5	2,4-Dinitrophenol	Deadly poison
121-14-2	2,4-Dinitrotoluene	Poison
606-20-2	2,5-Dinitrotoluene	Moderately toxic
117-84-0	n-Dioctyl phthalate	Mildly toxic
123-91-1	1,4-Dioxane	Poison
122-66-7	1,2-Diphenylhydrazine (Hydrazobenzene)	Poison
106-89-8	Epichlorohydrin	Poison
110-80-5	2-Ethoxyethanol	Moderately toxic
140-88-5	Ethyl acrylate	Poison
100-41-4	Ethylbenzene	Moderately toxic
541-41-3	Ethyl chloroformate	Poison
74-85-1	Ethylene	Simple asphyxiant
107-21-1	Ethylene glycol	Poison
151-56-4	Ethyleneimine (Aziridine)	Poison
75-21-8	Ethylene oxide	Poison
96-45-7	Ethylene thiourea	Poison
2164-17-2	Fluometuron	Poison
50-00-0	Formaldehyde	Poison
76-13-1	Freon 113	Mildly toxic
76-44-8	Heptachlor (1,4,5,6,7,8,8,-Heptachloro-3a,4,7,7a-tetrahydro-4,7-methano-1H-indene)	Poison
118-74-1	Hexachlorobenzene	Poison
87-68-3	Hexachloro-1,3-butadiene	Poison
77-47-4	Hexachlorocyclopentadiene	Deadly poison
67-72-1	Hexachloroethane	Poison
13355-87-1	Hexachloronaphthalene	Poison
680-31-9	Hexamethylphosphoramide	Experimental carcinogen
302-01-2	Hydrazine	Poison
10034-93-2	Hydrazine sulfate	Poison
7647-01-0	Hydrochloric acid	Poison
74-90-8	Hydrogen cyanide	Deadly poison
7664-39-3	Hydrogen fluoride	Poison
123-31-9	Hydroquinone	Poison
78-84-2	Isobutyraldehyde	Moderately toxic
67-63-0	Isopropyl alcohol	Poison
80-05-7	4,4-Isopropylidenediphenol	Poison
7439-92-1	Lead	Poison
58-89-9	Lindene	Poison
108-31-6	Maleic acid	Poison
12427-38-2	Maneb	Experimental carcinogen
7439-96-5	Manganese	Experimental tumorigen
108-78-1	Melamine	Experimental carcinogen

CAS NUMBER	CHEMICAL NAME	HAZARDS
7439-97-6	Mercury	Poison
67-56-1	Methanol	Poison
72-43-5	Methoxychlor (Benzene-1,1-(2,2,2,-trichloroethylidene)bis(4-methoxy)	Moderately toxic
109-86-4	2-Methoxyethanol	Moderately toxic
96-33-3	Methyl acrylate	Poison
1634-04-4	Methyl tert-butyl ether	Flammable
101-14-4	4,4-Methylenebis(2-chloro aniline)	Poison
101-61-1	4,4-Methylenebis (N,N-dimethyl)benzenamine	Moderately toxic
101-68-8	Methylenebis(phenylisocyanate)	Poison
74-95-3	Methylene bromide	Poison
101-77-9	4,4-Methylenedianiline	Poison
78-93-3	Methyl ethyl ketone	Moderately toxic
60-34-4	Methyl hydrazine	Poison
74-88-4	Methyl iodide	Poison
108-10-1	Methyl isobutyl ketone	Poison
624-83-9	Methyl isocyanate	Poison
80-62-6	Mehtyl methacrylate	Moderately toxic
90-94-8	Michler’s ketone	Poison
1313-27-5	Molybdenum trioxide	Poison
505-60-2	Mustard gas	Poison
91-20-3	Naphthalene	Poison
134-32-7	alpha-Naphthylamine	Poison
91-59-8	beta-Naphthylamine	Poison
7440-02-0	Nickel	Poison
7697-37-2	Nitric acid	Poison
139-13-9	Nitrilotriacetic acid	Poison
99-59-2	5-Nitro-o-anisidine	Moderately toxic
98-95-3	Nitrobenzene	Poison
92-93-3	4-Nitrobephenyl	Poison
1836-75-5	Nitrofen	Poison
51-75-2	Nitrogen mustard	Deadly poison
55-63-0	Nitroglycerin	Poison
88-75-5	2-Nitrophenol	Poison
100-02-7	4-Nitrophenol	Poison
79-46-9	2-Nitropropane	Poison
156-10-5	p-Nitrosodiphenylamine	Poison
121-69-7	N,N,-Dimethylaniline	Poison
924-16-3	N-Nitrosodi-n-butylamine	Moderately toxic
55-18-5	N-Nitrosodiethylamine	Poison
62-75-9	N-Nitrosodimethylamine	Poison
86-30-6	N-Nitrosodiohenylamine	Moderately toxic
621-64-7	N-Nitrosodi-n-propylamine	Moderately toxic
4549-40-0	N-Nitrosomethylvinylamine	Poison
59-89-2	N-Nitrosomorpholine	Poison
759-73-9	N-Nitroso-N-ethylurea	Poison
684-93-5	N-Nitroso-N-methylurea	Poison
16543-55-8	N-Nitrosonorrnicotine	Experimental carcinogen
100-75-4	N-Nitrosopiperidine	Poison
2234-13-1	Octachloronaphthlene	Poison
20816-12-0	Osmiun tetroxide	Poison
56-38-2	Parathion	Deadly poison
87-86-5	Pentachlorophenol	Poison
79-21-0	Peracetic acid	Poison
108-95-2	Phenol	Poison
106-50-3	p-Phenylenediamine	Poison
90-43-7	2-Phenylphenol	Poison
75-44-5	Phosgene	Poison
7664-38-2	Phosphoric acid	Poison
7723-14-0	Phosphorus	Poison
85-44-9	Phthalic anhydride	Poison
88-89-1	Picric acid	Poison

CAS NUMBER	CHEMICAL NAME	HAZARDS
1336-36-3	Polychlorinated biphenyls (PCBs)	Moderately toxic
1120-71-4	Propane sultone	Poison
57-57-8	beta-Propiolactone	Poison
123-38-6	Propionaldehyde	Moderately toxic
114-26-1	Propoxur	Poison
115-07-1	Propylene (propene)	Simple asphyxiant
75-55-8	Propyleneimine	Poison
75-56-9	Propylene oxide	Poison
110-86-1	Pyridine	Poison
91-22-5	Quinoline	Poison
106-51-4	Quinone	Poison
82-68-8	Quintozene (Pentachloronitrobenzene)	Experimental carcinogen
81-07-2	Saccharin	Moderately toxic
94-59-7	Safrole	Poison
7782-49-2	Selenium	Poison
7440-22-4	Silver	Experimental tumorigen
1310-73-2	Sodium hydroxide (solution)	Poison
7757-82-6	Sodium sulfate (solution)	Moderately toxic
100-42-5	Styrene	Experimental poison
96-09-3	Styrene oxide	Moderately toxic
7664-93-9	Sulfuric acid	Poison
100-21-0	Terephthalic acid	Moderately toxic
79-34-5	1,1,2,2,-Tetrachloroethane	Poison
127-18-4	Tetrachloroethylene	Experimental poison
961-11-5	Tetrachlorovinphos	Poison
7440-28-0	Thallium	Poison
62-55-5	Thioacetamide	Poison
139-65-1	4,4-Thiodianiline	Poison
62-56-6	Thiourea	Poison
1314-20-1	Thorium dioxide	Carcinogen
7550-45-0	Titanium tetrachloride	Poison
108-88-3	Toluene	Poison
584-84-9	Toulene-2,4-diisocyanate	Poison
91-08-7	Toluene-2,6-diisocyanate	Poison
95-53-4	o-Toluidine	Poison
636-21-5	o-Toluidine hydrochloride	Poison
8001-35-2	Toxaphene	Poison
68-76-8	Triaziquone	Poison
52-68-6	Trichlorfon (Phosphoric acid (2,2,2-trichloro-1-hydroxyethyl)-dimethyl ester	Poison
120-82-1	1,2,4-Trichlorobenzene	Poison
71-55-6	1,1,1-Trichloroethane (methyl chloroform)	Poison
79-00-5	1,1,2-Trichloroethane	Poison
79-01-6	Trichloroethylene	Experimental poison
95-95-4	2,4,5-Trichlorophenol	Poison
88-06-2	2,4,6-Trichlorophenol	Poison
1582-09-8	Trifluralin	Moderately toxic
95-63-6	1,2,4-Trimethylbenzene	Moderately toxic
126-72-7	Tris(2,3-dibromopropyl) phosphate	Poison
51-79-6	Urethane (Ethyl carbamate)	Moderately toxic
7440-62-2	Vanadium (fume or dust)	Poison
108-05-4	Vinyl acetate	Moderately toxic
593-60-2	Vinyl bromide	Moderately toxic
75-01-4	Vinyl chloride	Poison
75-35-4	Vinylidene chloride	Poison
1330-20-7	Xylene (mixed isomers)	Moderately toxic
108-38-3	m-Xylene	Moderately toxic
95-47-6	o-Xylene	Moderately toxic
106-42-3	p-Xylene	Moderately toxic
87-62-7	2,6-Xylidine	Moderately toxic
7440-66-6	Zinc (fume or dust)	Skin & systemic irritant
12122-67-7	Zineb	Moderately toxic

Chapter 12
Induced Damage Methods - Debris

12.1 Introduction

Very little has been done in the area of estimating debris from earthquakes. Some of the early regional loss estimation studies (e.g., Algermissen, et al., 1973; Rogers, et al., 1976) included some simplified models for estimating the amount of debris from shaking damage to unreinforced masonry structures. This methodology adopts a similar empirical approach to estimate two different types of debris. The first is debris that falls in large pieces, such as steel members or reinforced concrete elements. These require special treatment to break into smaller pieces before they are hauled away. The second type of debris is smaller and more easily moved with bulldozers and other machinery and tools. This includes brick, wood, glass, building contents and other materials. The methodology highlighting the Debris component is shown in Flowchart 12.1.

12.1.1 Scope

The module will estimate debris from building damage during earthquakes. No debris estimates are made for bridges or other lifelines.

12.1.2 Form of Damage Estimate

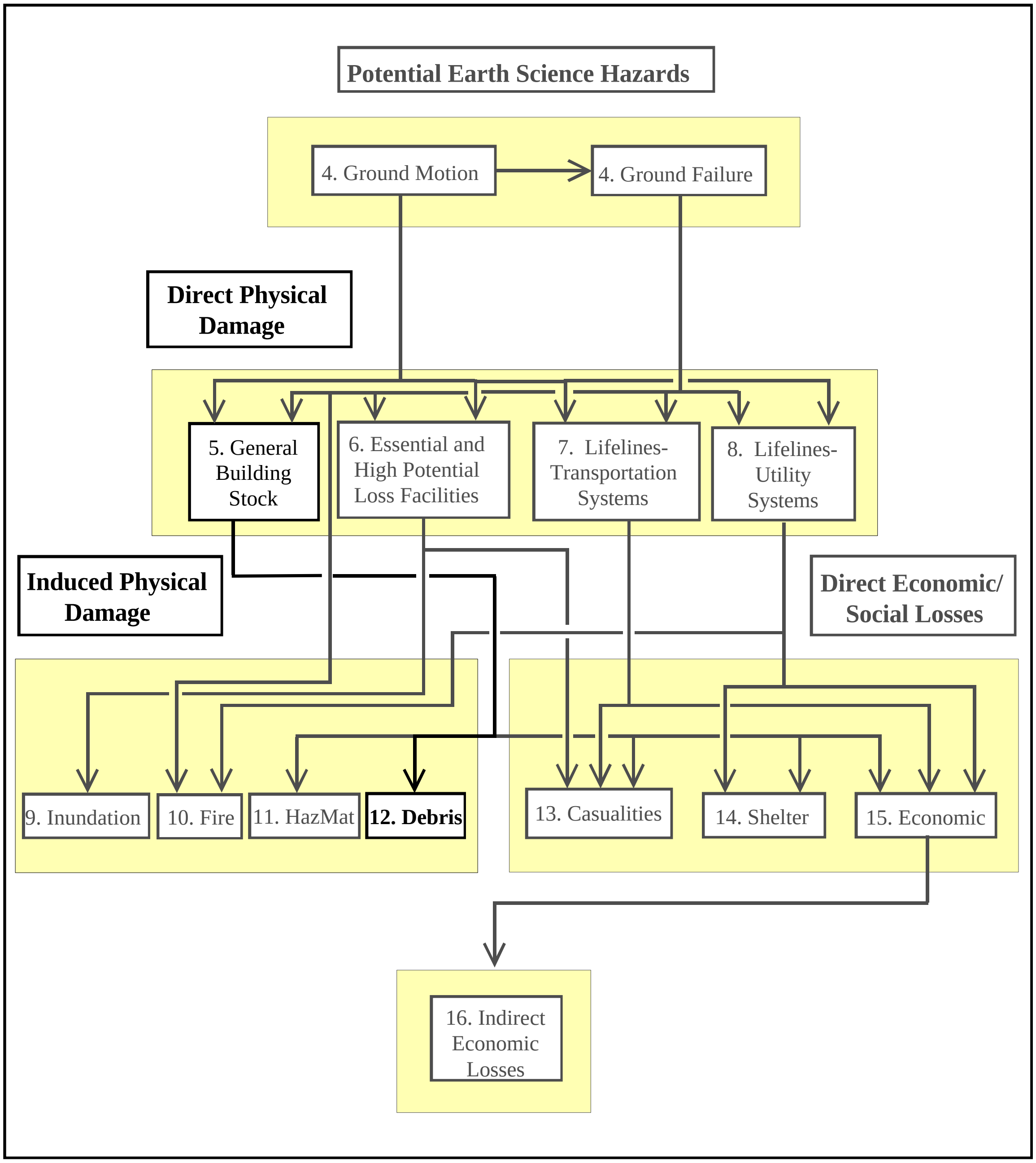
The module will determine the expected amounts of debris to be generated for each census tract. Output from this module will be the weight (tons) of debris. The classes of debris are defined as follows:

- Brick, wood and other
- Reinforced concrete and steel members

12.1.3 Input Requirements and Output Information

Input to this module includes the following items:

- Probabilities of structural and nonstructural damage states for model building types for each census tract provided from the direct physical damage module
- Square footage by occupancy class for each census tract provided from the inventory
- The occupancy to model building type relationship for each census tract



Flowchart 12.1: Debris Component Relationship to other Modules of the Earthquake Loss Estimation Methodology

12.2 Description of Methodology

The methodology for debris estimation is an empirical approach. That is, given the damage states for structural and nonstructural components, debris estimates are based on observations of damage that has occurred in past earthquakes and estimates of the weights of structural and nonstructural elements. The estimation can be made considering model building type, general occupancy class or specific occupancy class. In this section, the methodology described is based on model building types. Tables have been compiled to estimate generated debris from different structural and nonstructural damage states for each model building type. Given the distribution of different building types in square footage in each occupancy class, similar tables can also be compiled to estimate debris based on occupancy class.

12.2.1 Debris Generated From Damaged Buildings

Debris generated from damaged buildings (in tons) is based on the following factors:

- Unit weight of structural and nonstructural elements (tons per 1000 sq. ft. of floor area) for each of the model building types
- Probabilities of damage states for both structural and drift-sensitive nonstructural elements by census tract
- Square footage of each of the model building types by census tract
- Debris generated from different damage states of structural and nonstructural elements (% of unit weight of element)

The recommended values for unit weights of structural and nonstructural elements and debris generated per model building type are given in Tables 12.1, 12.2 and 12.3.

Table 12.1 Unit Weight (tons per 1000 ft^2) for Structural and Nonstructural Elements for the Model Building Types

#	Model Building Type	Brick, Wood and Other		Reinforced Concrete and Steel	
		Structural	Nonstructural	Structural	Nonstructural
1	W1	6.5	12.1	15.0	0.0
2	W2	4.0	8.1	15.0	1.0
3	S1L	0.0	5.3	44.0	5.0
4	S1M	0.0	5.3	44.0	5.0
5	S1H	0.0	5.3	44.0	5.0
6	S2L	0.0	5.3	44.0	5.0
7	S2M	0.0	5.3	44.0	5.0
8	S2H	0.0	5.3	44.0	5.0
9	S3	0.0	0.0	67.0	1.5
10	S4L	0.0	5.3	65.0	4.0
11	S4M	0.0	5.3	65.0	4.0
12	S4H	0.0	5.3	65.0	4.0
13	S5L	20.0	5.3	45.0	4.0
14	S5M	20.0	5.3	45.0	4.0
15	S5H	20.0	5.3	45.0	4.0
16	C1L	0.0	5.3	98.0	4.0
17	C1M	0.0	5.3	98.0	4.0
18	C1H	0.0	5.3	98.0	4.0
19	C2L	0.0	5.3	112.0	4.0
20	C2M	0.0	5.3	112.0	4.0
21	C2H	0.0	5.3	112.0	4.0
22	C3L	20.0	5.3	90.0	4.0
23	C3M	20.0	5.3	90.0	4.0
24	C3H	20.0	5.3	90.0	4.0
25	PC1	5.5	5.3	40.0	1.5
26	PC2L	0.0	5.3	100.0	4.0
27	PC2M	0.0	5.3	100.0	4.0
28	PC2H	0.0	5.3	100.0	4.0
29	RM1L	17.5	5.3	28.0	4.0
30	RM1M	17.5	5.3	28.0	4.0
31	RM2L	17.5	5.3	78.0	4.0
32	RM2M	24.5	5.3	78.0	4.0
33	RM2H	24.5	5.3	78.0	4.0
34	URML	35.0	10.5	41.0	4.0
35	URMM	35.0	10.5	41.0	4.0
36	MH	10.0	18.0	22.0	0.0

Table 12.2 Brick, Wood, and Other Debris Generated from Damaged Structural and Nonstructural Elements (in Fraction of Weight, %)

#	Building Type	Structural Damage State				Nonstructural Damage State			
		Slight	Moder	Exten	Comp	Slight	Moder	Exten	Comp
1	W1	0.0	5.0	34.0	100.0	2.0	8.0	35.0	100.0
2	W2	0.0	6.0	33.0	100.0	2.0	10.0	40.0	100.0
3	S1L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
4	S1M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
5	S1H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
6	S2L	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
7	S2M	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
8	S2H	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
9	S3	0.0	0.0	0.0	100.0	0.0	0.0	0.0	100.0
10	S4L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
11	S4M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
12	S4H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
13	S5L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
14	S5M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
15	S5H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
16	C1L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
17	C1M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
18	C1H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
19	C2L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
20	C2M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
21	C2H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
22	C3L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
23	C3M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
24	C3H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
25	PC1	0.0	6.0	32.0	100.0	2.0	11.0	42.0	100.0
26	PC2L	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
27	PC2M	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
28	PC2H	0.0	0.0	0.0	100.0	1.0	7.0	35.0	100.0
29	RM1L	3.5	20.0	50.0	100.0	2.0	10.0	40.0	100.0
30	RM1M	3.5	20.0	50.0	100.0	2.0	10.0	40.0	100.0
31	RM2L	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
32	RM2M	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
33	RM2H	5.0	25.0	60.0	100.0	1.0	7.0	35.0	100.0
34	URML	5.0	25.0	55.0	100.0	2.0	12.0	45.0	100.0
35	URMM	5.0	25.0	55.0	100.0	2.0	12.0	45.0	100.0
36	MH	0.0	5.0	33.0	100.0	2.0	8.0	35.0	100.0

Table 12.3 Reinforced Concrete and Wrecked Steel Generated from Damaged Structural and Nonstructural Elements (in Percentage of Weight)

#	Building Type	Structural Damage State				Nonstructural Damage State			
		Slight	Moder	Exten	Comp	Slight	Moder	Exten	Comp
1	W1	0.0	3.0	27.0	100.0	0.0	0.0	0.0	100.0
2	W2	0.0	2.0	25.0	100.0	0.0	10.0	28.0	100.0
3	S1L	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
4	S1M	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
5	S1H	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
6	S2L	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
7	S2M	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
8	S2H	0.0	4.0	30.0	100.0	0.1	8.0	28.0	100.0
9	S3	0.0	5.0	30.0	100.0	0.0	10.0	30.0	100.0
10	S4L	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
11	S4M	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
12	S4H	2.0	10.0	40.0	100.0	0.1	10.0	30.0	100.0
13	S5L	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
14	S5M	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
15	S5H	0.0	4.0	30.0	100.0	0.1	10.0	30.0	100.0
16	C1L	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
17	C1M	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
18	C1H	0.0	5.0	33.0	100.0	0.1	8.0	28.0	100.0
19	C2L	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
20	C2M	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
21	C2H	1.0	8.0	35.0	100.0	0.1	10.0	30.0	100.0
22	C3L	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
23	C3M	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
24	C3H	0.0	4.0	32.0	100.0	0.1	10.0	30.0	100.0
25	PC1	2.0	10.0	35.0	100.0	0.1	10.0	30.0	100.0
26	PC2L	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
27	PC2M	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
28	PC2H	2.0	7.0	35.0	100.0	0.1	9.0	30.0	100.0
29	RM1L	0.0	3.0	25.0	100.0	0.1	10.0	30.0	100.0
30	RM1M	0.0	3.0	25.5	100.0	0.1	10.0	31.0	100.0
31	RM2L	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
32	RM2M	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
33	RM2H	0.0	3.0	30.5	100.0	0.1	9.0	30.0	100.0
34	URML	0.0	2.0	25.0	100.0	0.0	10.0	29.0	100.0
35	URMM	0.0	2.0	25.0	100.0	0.0	10.0	29.0	100.0
36	MH	0.0	3.0	27.0	100.0	0.0	0.0	0.0	100.0

The following notation is used throughout the chapter.

- i - the iteration variable for the types of debris, i = 1 to 2
  - where: 1- brick, wood and other
  - 2- reinforced concrete and steel components
- j - the iteration variable for the damage states, j=1 to 5,
  - where: 1- none, 2- slight; 3- moderate; 4- extensive; 5- complete
- k - the iteration variable for the model building types, k=1 to 36

The inputs provided from direct physical damage module are the probabilities of different structural and nonstructural damage states. Thus, the first step in the debris calculation is to combine the debris fraction generated from the different damage states into the expected debris fraction for each model building type. The expected debris fraction for model building type k and debris type i due to structural damage is given by:

$$EDF_s(i,k) = \sum_{j=2}^{5} P_s(j,k) * DF_s(i,j,k) \tag{12-1}$$

where:

$EDF_s(i,k)$ - the expected debris fraction of debris type i due to structural damage for model building type k

$P_s(j,k)$ - the probability of structural damage state j for model building type k at the location being considered

$DF_s(i,j,k)$ - the debris fraction of debris type i for model building type k in structural damage state j (from Tables 12.2 and 12.3)

The expected debris fraction of debris type i due to nonstructural damage is given by:

$$EDF_{ns}(i,k) = \sum_{j=2}^{5} P_{ns}(j,k) * DF_{ns}(i,j,k) \tag{12-2}$$

where:

$EDF_{ns}(i,k)$ - the expected debris fraction of debris type i due to nonstructural damage for model building type k

$P_{ns}(j,k)$ - the probability of drift sensitive nonstructural damage state j for model building type k at the location being considered

$DF_{ns}(i,j,k)$ - the debris fraction of debris type i for model building type k in drift sensitive nonstructural damage state j (from Tables 12.2 and 12.3)

These values indicate the expected percentage of debris type i generated due to structural or nonstructural damage to model building type k. If we know the square footage of each model building type (by census tract), SQ(k), and weights of debris type i per 1000 ft^2 of building, $W_s(i,k)$ and $W_{ns}(i,k)$, then the amount of debris for this particular location can be obtained as follows:

$$DB(i) = \sum_{k=1}^{36} \left[EDF_s(i,k) * W_s(i,k) + EDF_{ns}(i,k) * \cdot W_{ns}(i,k) \right] * SQ(k) \qquad (12\text{-}3)$$

where:

$W_s(i,k)$ - the weight of debris type i per 1000 ft^2 of floor area for structural elements of model building type k (From Table 12.1)

$W_{ns}(i,k)$ - the weight of debris type i per 1000 ft^2 of floor area for nonstructural elements of model building type k; (From Table 12.1)

$SQ(k)$ - the census tract square footage for model building type k in thousands of square feet

DB(i) - the amount of debris type i (in tons)

12.3 Guidance for Expert-Generated Estimates

There is no difference in the methodology for Advanced Data and Models Analysis except more accurate input.

12.4 References

Algermissen, S. T., M. Hopper, K. Campbell, W. A. Rinehart, D. Perkins, K. V. Steinbrugge, H. J. Lagorio, D. F. Moran, F. S. Cluff, H. J. Degenkolb, C. M. Duke, G. O. Gates, N. N. Jacobson, R. A. Olson, and C. R. Allen. 1973. "A Study of Earthquake Losses in the Los Angeles, California Area." Washington, D.C.: National Oceanic and Atmospheric Administration (NOAA).

Rogers, A. M., S. T. Algermissen, W. W. Hays, D. M. Perkins, D. O. Van Strien, H. C. Hughes, R. C. Hughes, H. J. Lagorio, and K. V. Steinbrugge. 1976. "A Study of Earthquake Losses in the Salt Lake City, Utah Area" - USGS OFR 76-89. Washington, D.C.: United States Geological Survey.

Chapter 13
Direct Social Losses - Casualties

13.1 Introduction

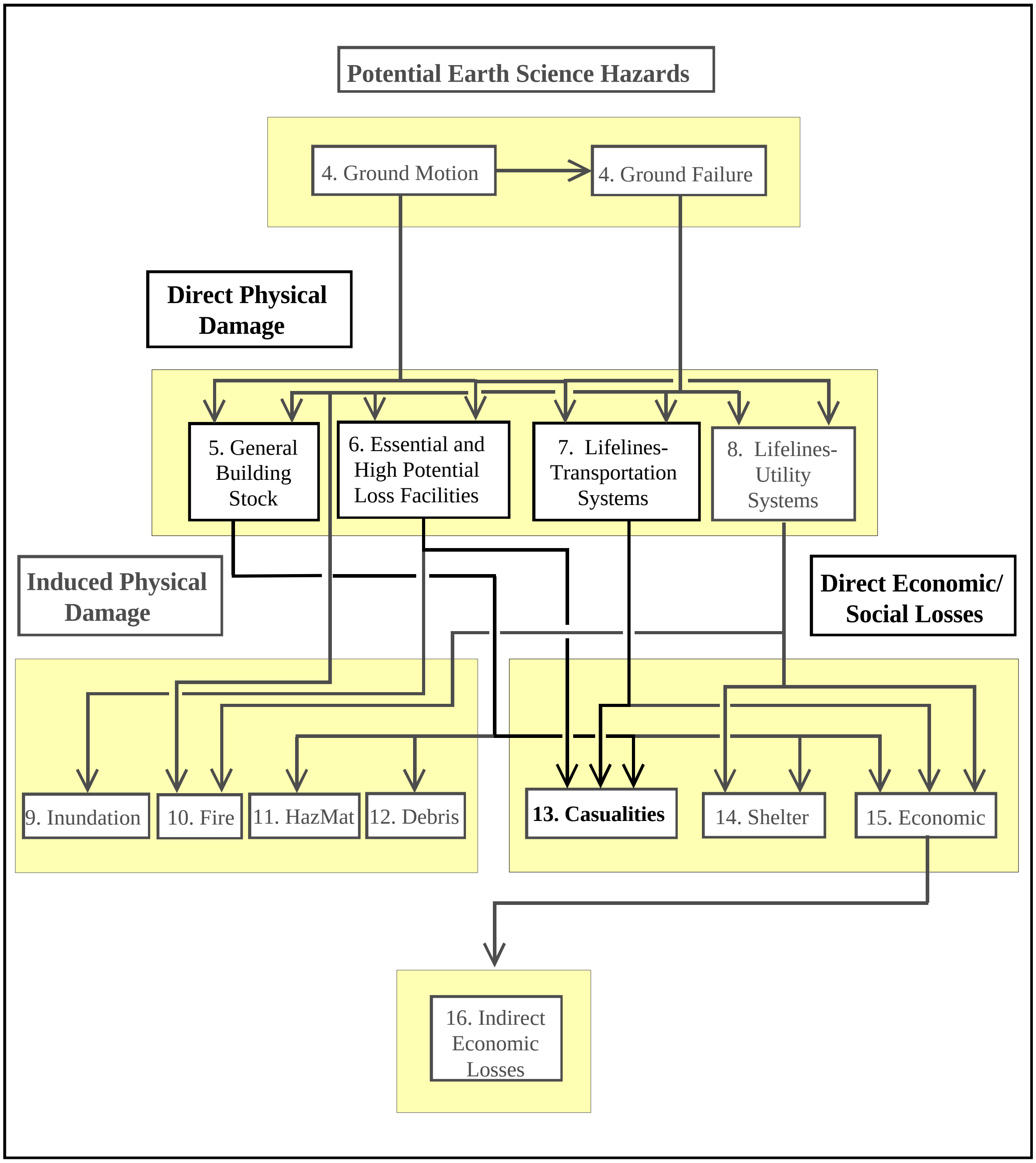
This chapter describes and develops the methodology for the estimation of casualties, describes the form of output, and defines the required input. The methodology is based on the assumption that there is a strong correlation between building damage (both structural and non-structural) and the number and severity of casualties. In smaller earthquakes, non-structural damage will most likely control the casualty estimates. In severe earthquakes where there will be a large number of collapses and partial collapses, there will be a proportionately larger number of fatalities. Data regarding earthquake related injuries is of limited quality and is not available for all building types. Available data often have insufficient information about the type of structure in which the casualties occurred and the casualty generating mechanism. Thus an attempt to develop very sophisticated models based on such data is neither feasible nor reliable. The methodology highlighting the Casualty component is shown in Flowchart 13.1.

13.1.1 Scope

This module provides a methodology for estimating casualties caused only by building damage. Although fire following earthquakes has been the cause of significant casualties (notably in the fire storm following the 1923 Kanto, Japan, earthquake), such cases have involved the combination of a number of conditions that are of low probability of occurrence in U.S. earthquakes. More typical is the catastrophic Oakland Hills fire of 1990, in which over 2000 residences were destroyed; yet casualties were low.

Similarly, there is the possibility of a large number of casualties due to sudden failure of a critical dam, or a massive release of toxic substances. If the particular characteristics of the study region give the user cause for concern about the possibility of casualties from fire, dam failure, or hazardous materials, it would be advisable to initiate specific studies directed towards the problem.

The scope of this module is to provide a simple and consistent framework for earthquake casualty estimation and formats for data collection and data sharing across the disciplines that are involved in casualty estimation. Many recognized relevant issues in casualty estimation such as occupancy potential, collapse and non-collapse vulnerability of the building stock, time of the earthquake occurrence, and spatial distribution of the parameters, are included in the methodology. The methodology is flexible enough to handle:



Flowchart 13.1: Direct Social Loss (Casualties) Relationship to other Components of the Earthquake Loss Estimation Methodology

- Domestic US casualty statistics
- Statistics derived from interpretation of worldwide casualty data
- Multidisciplinary input from professionals involved in earthquake casualty estimation

Data formats are flexible enough to handle currently available data, to re-evaluate previously collected data, and to accept new data as they become available.

13.1.2 Form of Casualty Estimate

The output from the module consists of a casualty breakdown by injury severity level, defined by a four level injury severity scale (Durkin and Thiel, 1991; Coburn, 1992; Cheu, 1994). Casualties are calculated at the census tract level. The output is at the census tract level and aggregated to the study region. Table 13.1 defines the injury classification scale used in the methodology.

Table 13.1: Injury Classification Scale

Injury Severity Level	Injury Description
Severity 1	Injuries requiring basic medical aid without requiring hospitalization
Severity 2	Injuries requiring a greater degree of medical care and hospitalization, but not expected to progress to a life threatening status
Severity 3	Injuries that pose an immediate life threatening condition if not treated adequately and expeditiously. The majority of these injuries are the result of structural collapse and subsequent entrapment or impairment of the occupants.
Severity 4	Instantaneously killed or mortally injured

Other, more elaborate casualty scales exist. They are based on quantifiable medical parameters such as medical injury severity scores, coded physiologic variables, etc. The selected four-level injury scale represents an achievable compromise between the demands of the medical community (in order to plan their response), and the ability of engineering community to provide the required data. For example, medical professionals would like to have the classification in terms of "Injuries/Illnesses" to account for worsened medical conditions caused by an earthquake (e.g., heart attack). However, currently available casualty assessment methodologies do not allow for a finer resolution in the casualty scale definition.

13.1.3 Input Requirements

There are three types of input data for the casualty module:

- Data defined by user
- Data supplied by other modules
- Data specific to the casualty module

Data Defined by User

The methodology provides information necessary to produce casualty estimates for three times of day. The following time options are provided:

- Earthquake striking at 2:00 a.m. (night time)
- Earthquake striking at 2:00 p.m. (day time)
- Earthquake striking at 5:00 p.m. (commute time)

These scenarios are expected to generate the highest casualties for the population at home, the population at work/school and the population during rush hour, respectively.

Data Supplied by Other Modules

The other modules provide the population distribution data, inventory (building stock distribution) data, and damage state probabilities. These data are provided at the census tract level. The values provided as defaults are best estimates made from available data. However, the user may modify the default database on the availability of improved information.

Population Distribution Data

The population for each census tract is distributed into four basic groups:

- Residential population
- Commercial population
- Industrial population
- Commuting population

The default population distribution is calculated for the three times of day for each census tract. Table 13.2 provides the relationships used to determine the default distribution. The population distribution was based on Census data and Dun and Bradstreet data and has an inherent error associated with the distribution. If the user has a better understanding about the distribution of the working/school population among census tracts, the default information should be modified to reflect the improved knowledge.

The commuting population is defined as the number of people expected on the roadways during the commuting time. In this methodology, the only roadway casualties estimated are those incurred from bridge/overpass damage. This requires the user to estimate the number of people located on or under bridges during the seismic event. The methodology provides for a user-defined commuter distribution factor, CDF that corresponds to the percentage of the commuting population located on or under bridges. The number of people on or under bridges in a census tract is then computed as follows.

$$NBRDG = CDF * COMM \qquad (13\text{-}1)$$

where:

NBRDG	Number of people on or under bridges in the census tract
CDF	Percent of commuters on or under bridges in census tract (Commuter Distribution Factor)
COMM	Number of commuters in census tract

Table 13.2: Default Relationships for Estimating Population Distribution

Distribution of People in Census Tract			
Basic Group	**2:00 a.m.**	**2:00 p.m.**	**5:00 p.m.**
Residential	0.99(NRES)	0.80(DRES)	0.95(DRES)
Commercial	0.02(COMW)	0.98(COMW) + 0.15(DRES) + 0.80(AGE_16)	0.50(COMW)
Industrial	0.10(INDW)	0.80(INDW)	0.50(INDW)
Commuting	0.01(POP)	0.05(POP)	0.05(DRES) + 1.0(COMM)

where:

POP	is the census tract population taken from census data
DRES	is the daytime residential population inferred from census data
NRES	is the nighttime residential population inferred from census data
COMM	is the number of people commuting inferred from census data
COMW	is the number of people employed in the commercial sector
INDW	is the number of people employed in the industrial sector.
AGE_16	is the number of people 16 years of age and under inferred from census data (used as a proxy for the portion of population located in schools)

The User's Manual will provide the user with guidance on how to determine an appropriate value for CDF. The methodology defaults the CDF to assumed values of 0.05 during the day and night time and 0.10 for the commuting time. Local data on the percentage of commuters on or under highway bridges would provide greater accuracy.

General Occupancy to Model Building Type Mapping

The model uses the relationship between the general occupancy classes and the model building type that is calculated by combining the following relationships.

- Specific Occupancy to Model Building Type Relationship
- General Occupancy to Specific Occupancy Relationship

Damage State Probabilities

The casualty model uses the four structural damage states computed by the other modules: slight, moderate, extensive, and complete. For each census tract and each building type and bridge type, the probabilities of the structure being in each of the four damage states is provided by the software.

Data Specific to The Casualty Module

This module limits itself to the estimation of casualties that would be caused by damage to buildings and bridges. Excluded are casualties or health effects not due to immediate physical impact, such as heart attacks, psychological effects, or injuries suffered during post-earthquake clean-up or construction activities. Exterior casualties caused from collapsing masonry parapets or pieces of bearing walls or from falling signs and other appendages are also excluded. The casualty rates used in the methodology are relatively uniform across building types for a given damage level, with differentiation to account for types of construction that pose higher-than-average hazards at moderate damage levels (e.g., falling of pieces of unreinforced masonry) or at severe levels (e.g., complete collapse of heavy concrete construction as compared to wood frame construction). Rates used in the ATC-13 method were evaluated and revised based on comparison with a limited amount of historical data. For the Northridge Earthquake, the casualties estimated by the methodology are a reasonably representation of the actual numbers observed.

The following default casualty rates are defined by the methodology.

- Casualty rates by model building type for slight structural damage
- Casualty rates by model building type for moderate structural damage
- Casualty rates by model building type for extensive structural damage
- Casualty rates by model building type for complete structural damage without structural collapse
- Casualty rates by model building type for complete structural damage with structural collapse
- Collapse rates by model building type for complete structural damage state.
- Casualty rates for bridges with complete structural damage

It should be noted that only a portion of the buildings in the complete damage state are considered to be collapsed. The relevant percentages for each model building type are given in Chapter 5. Tables 13.3 through 13.9 define the values for the default casualty module data.

Table 13.3: Casualty Rates by Model Building Type for Slight Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.05	0.005	0	0
2	W2	0.05	0.005	0	0
3	S1L	0.05	0.005	0	0
4	S1M	0.05	0.005	0	0
5	S1H	0.05	0.005	0	0
6	S2L	0.05	0.005	0	0
7	S2M	0.05	0.005	0	0
8	S2H	0.05	0.005	0	0
9	S3	0.05	0.005	0	0
10	S4L	0.05	0.005	0	0
11	S4M	0.05	0.005	0	0
12	S4H	0.05	0.005	0	0
13	S5L	0.05	0.005	0	0
14	S5M	0.05	0.005	0	0
15	S5H	0.05	0.005	0	0
16	C1L	0.05	0.005	0	0
17	C1M	0.05	0.005	0	0
18	C1H	0.05	0.005	0	0
19	C2L	0.05	0.005	0	0
20	C2M	0.05	0.005	0	0
21	C2H	0.05	0.005	0	0
22	C3L	0.05	0.005	0	0
23	C3M	0.05	0.005	0	0
24	C3H	0.05	0.005	0	0
25	PC1	0.05	0.005	0	0
26	PC2L	0.05	0.005	0	0
27	PC2M	0.05	0.005	0	0
28	PC2H	0.05	0.005	0	0
29	RM1L	0.05	0.005	0	0
30	RM1M	0.05	0.005	0	0
31	RM2L	0.05	0.005	0	0
32	RM2M	0.05	0.005	0	0
33	RM2H	0.05	0.005	0	0
34	URML	0.05	0.005	0	0
35	URMM	0.05	0.005	0	0
36	MH	0.05	0.005	0	0

Table 13.4: Casualty Rates by Model Building Type for Moderate Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	0.2	0.02	0	0
2	W2	0.2	0.02	0	0
3	S1L	0.2	0.02	0	0
4	S1M	0.2	0.02	0	0
5	S1H	0.2	0.02	0	0
6	S2L	0.2	0.02	0	0
7	S2M	0.2	0.02	0	0
8	S2H	0.2	0.02	0	0
9	S3	0.2	0.02	0	0
10	S4L	0.2	0.02	0	0
11	S4M	0.2	0.02	0	0
12	S4H	0.2	0.02	0	0
13	S5L	0.2	0.02	0	0
14	S5M	0.2	0.02	0	0
15	S5H	0.2	0.02	0	0
16	C1L	0.2	0.02	0	0
17	C1M	0.2	0.02	0	0
18	C1H	0.2	0.02	0	0
19	C2L	0.2	0.02	0	0
20	C2M	0.2	0.02	0	0
21	C2H	0.2	0.02	0	0
22	C3L	0.2	0.02	0	0
23	C3M	0.2	0.02	0	0
24	C3H	0.2	0.02	0	0
25	PC1	0.2	0.02	0	0
26	PC2L	0.2	0.02	0	0
27	PC2M	0.2	0.02	0	0
28	PC2H	0.2	0.02	0	0
29	RM1L	0.2	0.02	0	0
30	RM1M	0.2	0.02	0	0
31	RM2L	0.2	0.02	0	0
32	RM2M	0.2	0.02	0	0
33	RM2H	0.2	0.02	0	0
34	URML	0.4	0.04	0	0
35	URMM	0.4	0.04	0	0
36	MH	0.2	0.02	0	0

Table 13.5: Casualty Rates by Model Building Type for Extensive Structural Damage

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	1	0.1	0.001	0.001
2	W2	1	0.1	0.001	0.001
3	S1L	1	0.1	0.001	0.001
4	S1M	1	0.1	0.001	0.001
5	S1H	1	0.1	0.001	0.001
6	S2L	1	0.1	0.001	0.001
7	S2M	1	0.1	0.001	0.001
8	S2H	1	0.1	0.001	0.001
9	S3	1	0.1	0.001	0.001
10	S4L	1	0.1	0.001	0.001
11	S4M	1	0.1	0.001	0.001
12	S4H	1	0.1	0.001	0.001
13	S5L	1	0.1	0.001	0.001
14	S5M	1	0.1	0.001	0.001
15	S5H	1	0.1	0.001	0.001
16	C1L	1	0.1	0.001	0.001
17	C1M	1	0.1	0.001	0.001
18	C1H	1	0.1	0.001	0.001
19	C2L	1	0.1	0.001	0.001
20	C2M	1	0.1	0.001	0.001
21	C2H	1	0.1	0.001	0.001
22	C3L	1	0.1	0.001	0.001
23	C3M	1	0.1	0.001	0.001
24	C3H	1	0.1	0.001	0.001
25	PC1	1	0.1	0.001	0.001
26	PC2L	1	0.1	0.001	0.001
27	PC2M	1	0.1	0.001	0.001
28	PC2H	1	0.1	0.001	0.001
29	RM1L	1	0.1	0.001	0.001
30	RM1M	1	0.1	0.001	0.001
31	RM2L	1	0.1	0.001	0.001
32	RM2M	1	0.1	0.001	0.001
33	RM2H	1	0.1	0.001	0.001
34	URML	2	0.2	0.002	0.002
35	URMM	2	0.2	0.002	0.002
36	MH	1	0.1	0.001	0.001

Table 13.6: Casualty Rates by Model Building Type for Complete Structural Damage (No Collapse)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	5	1	0.01	0.01
2	W2	5	1	0.01	0.01
3	S1L	5	1	0.01	0.01
4	S1M	5	1	0.01	0.01
5	S1H	5	1	0.01	0.01
6	S2L	5	1	0.01	0.01
7	S2M	5	1	0.01	0.01
8	S2H	5	1	0.01	0.01
9	S3	5	1	0.01	0.01
10	S4L	5	1	0.01	0.01
11	S4M	5	1	0.01	0.01
12	S4H	5	1	0.01	0.01
13	S5L	5	1	0.01	0.01
14	S5M	5	1	0.01	0.01
15	S5H	5	1	0.01	0.01
16	C1L	5	1	0.01	0.01
17	C1M	5	1	0.01	0.01
18	C1H	5	1	0.01	0.01
19	C2L	5	1	0.01	0.01
20	C2M	5	1	0.01	0.01
21	C2H	5	1	0.01	0.01
22	C3L	5	1	0.01	0.01
23	C3M	5	1	0.01	0.01
24	C3H	5	1	0.01	0.01
25	PC1	5	1	0.01	0.01
26	PC2L	5	1	0.01	0.01
27	PC2M	5	1	0.01	0.01
28	PC2H	5	1	0.01	0.01
29	RM1L	5	1	0.01	0.01
30	RM1M	5	1	0.01	0.01
31	RM2L	5	1	0.01	0.01
32	RM2M	5	1	0.01	0.01
33	RM2H	5	1	0.01	0.01
34	URML	10	2	0.02	0.02
35	URMM	10	2	0.02	0.02
36	MH	5	1	0.01	0.01

Table 13.7: Casualty Rates by Model Building Type for Complete Structural Damage (With Collapse)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
1	W1	50	10	1	1
2	W2	50	10	2	2
3	S1L	50	10	2	2
4	S1M	50	10	2	2
5	S1H	50	10	2	2
6	S2L	50	10	2	2
7	S2M	50	10	2	2
8	S2H	50	10	2	2
9	S3	50	10	1	1
10	S4L	50	10	2	2
11	S4M	50	10	2	2
12	S4H	50	10	2	2
13	S5L	50	10	2	2
14	S5M	50	10	2	2
15	S5H	50	10	2	2
16	C1L	50	10	2	2
17	C1M	50	10	2	2
18	C1H	50	10	2	2
19	C2L	50	10	2	2
20	C2M	50	10	2	2
21	C2H	50	10	2	2
22	C3L	50	10	2	2
23	C3M	50	10	2	2
24	C3H	50	10	2	2
25	PC1	50	10	2	2
26	PC2L	50	10	2	2
27	PC2M	50	10	2	2
28	PC2H	50	10	2	2
29	RM1L	50	10	2	2
30	RM1M	50	10	2	2
31	RM2L	50	10	2	2
32	RM2M	50	10	2	2
33	RM2H	50	10	2	2
34	URML	50	10	2	2
35	URMM	50	10	2	2
36	MH	50	10	1	1

Table 13.8: Collapse Rates by Model Building Type for Complete Structural Damage

	Model Building Type	Probability of Collapse Given a Complete Damage State*
1	W1	5%
2	W2	5%
3	S1L	20%
4	S1M	15%
5	S1H	10%
6	S2L	20%
7	S2M	15%
8	S2H	10%
9	S3	25%
10	S4L	20%
11	S4M	15%
12	S4H	10%
13	S5L	25%
14	S5M	20%
15	S5H	15%
16	C1L	20%
17	C1M	15%
18	C1H	10%
19	C2L	20%
20	C2M	15%
21	C2H	10%
22	C3L	25%
23	C3M	20%
24	C3H	15%
25	PC1	25%
26	PC2L	25%
27	PC2M	20%
28	PC2H	15%
29	RM1L	20%
30	RM1M	15%
31	RM2L	20%
32	RM2M	15%
33	RM2H	10%
34	URML	25%
35	URMM	25%
36	MH	5%

* See Chapter 5 for derivation of these values

13.2 Description of Methodology

The casualty model is complementary to the concepts put forward by some other models (Coburn and Spence, 1992; Murkami, 1992, Shiono, et. al., 1991). The Coburn and Spence model uses the same four-level injury severity scale (light injuries, hospitalized injuries, life threatening injuries and deaths) and underlying concepts associated with building collapse. However, it is not in event tree format and does not account for non-collapse (damage) related casualties, nor does it account for the population not indoors at the time of earthquake. The Murkami model is an event tree model that includes only fatalities caused by collapsed buildings and does not account for injuries. Shiono's model is similar to the other two models and only estimated fatalities.

The methodology takes into account a wider range of causal relationships in the casualty modeling. It is an extension of the model proposed by Stojanovski and Dong (1994).

13.2.1 Earthquake Casualty Model

Casualties caused by a postulated earthquake can be modeled by developing a tree of events leading to their occurrence. As with any event tree, the earthquake-related casualty event tree begins with an initiating event (earthquake scenario) and follows the possible course of events leading to loss of life or injuries. The logic of its construction is forward (inductive). At each node of the tree, the (node branching) question is: What happens if the preceding event leading to the node occurs? The answers to this question are the branches of the tree. The number of branches from any node is equal to the number of answers selected as relevant to the node branching question. Each branch of the tree is assigned a probability of occurrence. For earthquake related casualties, some of these probabilities cannot be obtained as long run relative frequencies because earthquakes (the initiating events) are rare events and long run frequencies are not available. One possibility is to infer them from the available data statistics, combined with expert opinion, classical statistical and Bayesian inference. Therefore, the assigned probabilities in this case are subjective, and the probability itself may be subjectively defined as degree of belief that an event will occur.

For example, to choose one severity of casualty, the expected number of occupants killed in a building during a given earthquake could be simulated with an event tree, as shown in Figure 13.1. For illustrative purposes it contains as events of interest "occupants killed", only. Evaluation of the branching probabilities constitutes the main effort in the earthquake casualty modeling. Assuming that all the branching probabilities are known or inferred, the probability of an occupant being killed (P_{killed}) is given as follows.

$$P_{killed} = P_A * P_E + P_B * P_F + P_C * P_G + P_D * (P_H * P_J + P_I * P_K) \qquad (13\text{-}2)$$

By introducing the substitutions

$$P_{killed \mid collapse} = P_D * P_I * P_K \qquad (13\text{-}3)$$

and

$$P_{killed \mid no\text{-}collapse} = P_A * P_E + P_B * P_F + P_C * P_G + P_D * P_H * P_J \qquad (13\text{-}4)$$

Equation (13-1) could be simply re-written as:

$$P_{killed} = P_{killed \mid collapse} + P_{killed \mid no\text{-}collapse} \qquad (13\text{-}5)$$

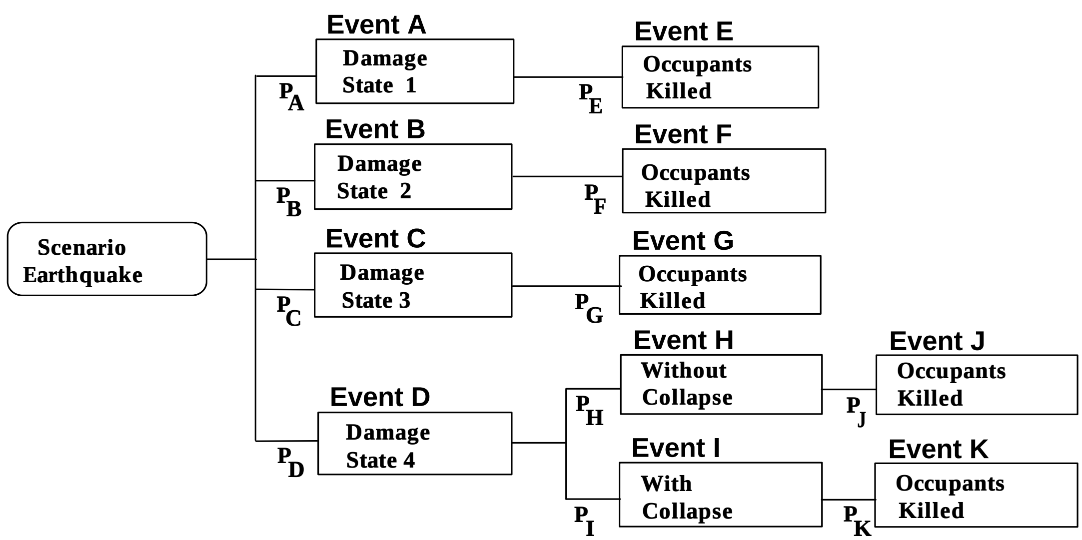


Figure 13.1: Casualty Event Tree Modeling.

The first term in equation 13-5 is associated with the building collapse. The second term is associated with the level of non-collapse damage the building sustains during the earthquake. Records from past earthquakes show that for different regions in the world with different kind of construction there are different threshold intensities at which the first term begins to dominate. For intensities below that shaking level, casualties are primarily damage or non-collapse related. For intensities above that level, the collapse, often of only a few structures, may control the casualty pattern.

The expected number of occupants killed ($EN_{occupants\ killed}$) is a product of the number of occupants of the building at the time of earthquake ($N_{occupants}$) and the probability of an occupant being killed (P_{killed}).

$$EN_{occupants\ killed} = N_{occupants} * P_{killed} \qquad (13\text{-}6)$$

The general earthquake related casualty estimation problem is more complex than the presented example. Problems of similar or higher complexity have been successfully tackled by event tree or fault tree simulation in the field of industrial safety and industrial reliability since the early 1960s.

Figure 13.2 presents a more complete earthquake related casualty event tree, which is used in the methodology. The branching probabilities are not shown in the figure in order to make the model presentation simpler. The events are represented with rectangular boxes. A short event or state description is given in the boxes.

The symbol "<" attached to the event box means that branching out from that node is identical to branching for the same category event (obviously, the appropriate probabilities would be different).

The event tree in Figure 13.2 is conceptual. It integrates several different event trees into one (light injuries, hospitalized injuries, life threatening injuries and deaths) for different types (residential, commercial, industrial, commuting). Casualty rates are different depending on the preceding causal events: damage state, collapse, population indoors, etc.

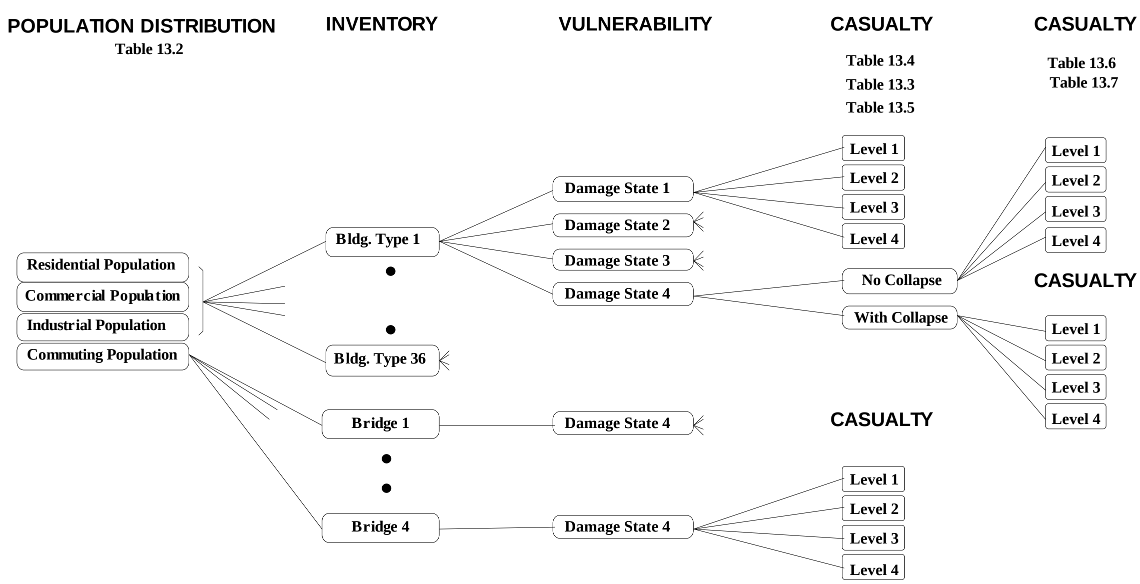


Figure 13.2: Casualty Event Tree Model.

The model is capable of using the best available non-region-specific casualty rates. This capability is attributed to the property of the event tree analysis: that all branching probabilities are conditional upon the occurrence of the node associated event. If average worldwide casualty statistics or data from one or few other countries are to be used for collapse-related casualty modeling in the United States, special attention must be given to the relationship between the U.S. structural types and the structural types represented by these other data sets. Also, appropriate mapping between injury classification scales must be established. Finally, it is possible that differing levels of earthquake preparedness, such as the effectiveness of the emergency health system, and the training of the public in personal protective measures, such as "duck and cover", might cause U.S. casualty rates to differ from those overseas, but this is unlikely to be a significant factor in cases of collapse, and at the present no data is available on these kinds of issues.

13.2.2 Alternative Estimation of Casualty Rates

In earthquakes that don't cause significant collapse, a significant portion of the casualty total is caused to nonstructural damage, accidents, medical conditions, etc. which make the casualty contributing factors difficult to predict and quantify. Occupant contact with nonstructural elements and building contents is a major source of minor injuries in this case, with a much smaller proportion of serious injuries and deaths. Occupant actions may also contribute to injuries, e.g., while attempting to take evasive action (Durkin, 1992).

In the absence of adequate U.S.-specific casualty data (as a consequence of structural collapse), international data on the casualty rates for specific structural types may be used. This means that U.S. construction practices, design and construction quality would have to be reflected in the appropriate region-specific fragility curves. Published data on collapse-related casualty rates is limited. Noji (Noji, E.K., "Epidemic Studies from the 1988 Armenia Earthquake: Implications for Casualty Modeling", Workshop on Earthquake Casualty Modeling, Asilomar, California, December 4-6, 1990) provided this type of data for stone masonry and precast concrete buildings. Murakami (1992) used these rates in a model that simulated the fatalities from the same event. Durkin and Murakami (1989) reported casualty rates for two reinforced concrete buildings collapsed during the 1985 Mexico and 1986 San Salvador earthquakes. Shiono at al. (1991) provided fatality rates after collapse for most common worldwide structural types. Coburn et al. (1992) have summarized approximate casualty rates for masonry and reinforced concrete structures based on worldwide data.

The casualty patterns for people who evacuate collapsed buildings, either before or immediately after the collapse, are more difficult to quantify. Statistical data on these casualty patterns is lacking, since in most post-earthquake reconnaissance efforts these injuries are not distinguished from other causes of injuries. In some cases, the lighter injuries may not be reported. An assumption that those who manage to evacuate are neither killed nor receive life threatening injuries, may be applied. Often it is assumed that 50% of the occupants of the first floor manage to evacuate.

Experience in a number of earthquakes overseas and in the United States has shown that a number of casualties occur outside buildings due to falling materials. In the United States these casualties have been caused primarily by falling unreinforced masonry, which may cause damage to an adjoining building and result in casualties, or, fall directly on people outside the building. It is suggested that planners should investigate their building stock, particularly with respect to a high intensity of URM buildings located where damage might be caused to other buildings or where people congregate, and consider adding some casualties to the estimates if potential dangerous situations are revealed. To accomplish this, the number of people would be on sidewalks or similar exterior areas must be estimated. This sum must not be double-counted with the calculation of building occupants.

13.2.3 Casualty Rates Resulting from Bridge Collapse

Casualty rates are provided in Table 13.9 (Casualty Rates for Complete Structural damage) for bridges that have been completely damaged. Lack of data did not allow similar inferences for other damage states.

<u>Single Span Bridges</u>

The only reference which reports on many aspects of a single span bridge collapse is "Loma Prieta Earthquake October 17, 1989; I-80 San Francisco - Oakland Bay Bridge, Closure Span Collapse", published by the Department of California Highway Patrol in 1990. This document systematically reports most of the facts related to the collapse of the bridge.

During the Loma Prieta earthquake the closure spans collapsed. The only fatality was recorded approximately half an hour after the event when a car fell into the gap created by the collapse.

Table 13.9: Casualty Rates for Bridges (Complete Structural Damage)

#	Building Type	Casualty Severity Level			
		Severity 1 (%)	Severity 2 (%)	Severity 3 (%)	Severity 4 (%)
B1	Major Bridge	17	20	37	7
B2	Continuous Bridge	17	20	37	7
B3	Single Span Bridge	5	25	20	5

Major and Continuous Bridges

The only reference which reports on many aspects of a continuous (major) bridge collapse is "Loma Prieta Earthquake October 17, 1989; I-880 Cypress Street Viaduct Structure Collapse", published by the Department of California Highway Patrol in 1990. This reference systematically reports most of the facts related to the collapse of the bridge.

Most of the injuries and fatalities occurred on the lower northbound deck as a consequence of the collapse of the upper deck onto the lower deck. A significant portion of injuries and fatalities also occurred among the people driving on the upper southbound deck. A small portion of casualties resulted from vehicles on the surface streets adjacent to the collapsed structure.

For casualty rates for major and continuous bridges, casualty statistics on the upper deck of the Cypress Viaduct and on the adjacent surface streets have been used. Casualties associated with the vehicles on the lower deck are not considered representative because double deck bridges and freeways are not common.

13.3 References

Allen and Hoshall, Jack R. Benjamin and Associates, and Systan Inc. 1985. *An Assessment of Damage and Casualties for Six Cities in the Central United States Resulting from Earthquakes in the New Madrid Seismic Zone*. Prepared for FEMA.

Aroni, S., and Durkin, M. E. 1985, "Injuries and Occupant Behavior in Earthquakes", *Proc. Joint U.S. - Romanian Seminar on Earthquake & Energy*, Bucharest, Romania, Vol. 2, September: 3 - 40.

ATC - 13 (1985), Earthquake Damage Evaluation Data for California, Applied Technology Council, Redwood City, CA.

Brismar, B. (1989), "The Medical Severity Index of Disasters," *Proc. International Workshop on Earthquake Injury Epidemiology*, The John Hopkins University, July: 316 - 320.

Charter of the U.S. Ad Hoc Working Group on the Health Effects of Earthquakes (1992), *First International Forum on Earthquake Related Casualties*, Madrid, Spain, July: 22 - 26.

Cheu, D. H. (1994), Personal Communication - Comments on Casualty Issues, April.

Coburn, A.W. and Spence, R.J.S.(1992), "Factors Determining Human Casualty Levels in Earthquakes: Mortality Prediction in Building Collapse", *Proceedings of the 10 WCEE*, Madrid, Spain: 5989 - 5994.

Durkin, M. E. and Thiel, C. C. 1993, "Toward a Comprehensive Regional Earthquake Casualty Modeling Process", *Proc. National Earthquake Conference, Vol. I*, Central U.S. Earthquake Consortium, May: 557 - 566.

Durkin, M.E. (1992), "Improving Earthquake Casualty and Loss Estimation", *Proc. 10 WCEE*, Madrid, Spain: 557 - 562.

Durkin, M.E. and Thiel, C.C. (1991), "Integrating Earthquake Casualty and Loss Estimation", *Proc. of the Workshop on Modeling Earthquake Casualties for Planning and Response*, Sacramento.

Durkin, M. and Murakami, H. (1989), "Casualties, Survival, and Entrapment in Heavily Damaged Buildings", *Proc. 9 WCEE*, Kyoto, Japan: Vol. VII, 977 - 982..

Fussell, J. (1976), "Fault Tree Analysis - Concepts and Techniques", *Generic Techniques in Reliability Assessment*, Henley, E. and Lynn, J. (eds.), Noordhoff Publishing Co., Leyden, Holland.

Golden Gate Divisional Multidisciplinary Accident Investigation Team (MAIT) (1990), "*I-80 San Francisco-Oakland Bay Bridge Structure Collapse Report*", California Highway Patrol, Sacramento, CA.

Golden Gate Divisional Multidisciplinary Accident Investigation Team (MAIT) (1990), "*I-880 Nimitz Freeway (Cyress viaduct) Structure Collapse Report*", California Highway Patrol, Sacramento, CA.

Haney, T. (1990), "Model Definition and User Output Requirements", *Proc. Workshop on Modeling Earthquake Casualties for Planning and Response*, Pacific Grove, CA, December: A1 - A11.

Henley, E.J. and Kumamoto, H., 1992, *Probabilistic Risk Assessment - Reliability Engineering, Design, and Analysis,* IEEE.

Jones, N.P., Noji, E.K., Smith, G.S. and Wagner, R.M. (1993), "Casualty in Earthquakes", *Monograph 5 - Socioeconomic Impacts, National Earthquake Conference, Memphis, Tennessee,* Central U.S. Earthquake Consortium, May: 19 - 68.

Jones, N.P., Wagner R.M. and Smith, G.S., 1993, "Injuries and Building Data Pertinent to the Loma Prieta Earthquake: County of Santa Cruz", *Proc. National Earthquake Conference,* Vol. I, Central United States Earthquake Consortium: 531 - 540.

Jones, N P., 1990, "Reducing Earthquake Casualties: New Considerations for Engineers", *Proc. Conference XLIX - A Meeting of the U.S. Ad Hoc Working Group on Earthquake Related Casualties,* U.S.G.S. Open File Report 90244, Reston, Virginia: 60 - 70.

Krimgold, F., 1992, "Current Application of Casualty Information for Loss Estimation and Post Earthquake Response", *First International Forum on Earthquake Related Casualties,* Madrid, Spain, May: 21 - 30.

Murkami H. O., 1992, "A Simulation Model to Estimate Human Loss for Occupants of Collapsed Buildings in an Earthquake", *Proceedings of the 10. WCEE,* Madrid, Spain: 5969 - 5974.

Shiono, K., Krimgold, F. and Ohta, Y., 1991, "A Method for the Estimation of Earthquake Fatalities and its Applicability to the Global Macro-Zonation of Human Casualty Risk", *Proc. Fourth International Conference on Seismic Zonation*, Stanford, CA, Vol. III: 277 - 284.

Shiono, K., Krimgold, F., Ohta, Y., 1991, "Post-Event Rapid Estimation of Earthquake Fatalities for the Management of Rescue Activity", *Comprehensive Urban Studies*, No. 44, pp. 61 - 105.

Stojanovski, P., Dong, W., 1994, "Simulation Model for Earthquake Casualty Estimation", *Proc. Fifth U.S. National Conference on Earthquake Engineering*, Paper No. 00592, Chicago, Illinois, July 10-14.

Tierney, J. T., 1990, "Developing Multivariate Models for Earthquake Casualty Estimation", *Proc. Workshop on Modeling Earthquake Casualties for Planning and Response*, Pacific Grove, CA, December: D1 - D24.

Chapter 14
Direct Social Losses - Displaced Households Due to Loss of Housing Habitability and Short Term Shelter Needs

14.1 Introduction

Earthquakes can cause loss of function or habitability of buildings that contain housing units, resulting in approximately predictable numbers of displaced households. These households may need alternative short-term shelter, provided by family, friends, renting apartments or houses, or public shelters provided by relief organizations such as the Red Cross, Salvation Army, and others. For units where repair takes longer than a few weeks, long-term alternative housing can be accommodated by importing mobile homes, occupancy of vacant units, net emigration from the impacted area, and, eventually, by the repair or reconstruction of new public and private housing. While the number of people seeking short-term public shelter is of great concern to emergency response organizations, the longer-term impacts on the housing stock are of great concern to local governments, such as cities and counties. The methodology highlighting the Shelter component is shown in Flowchart 14.1.

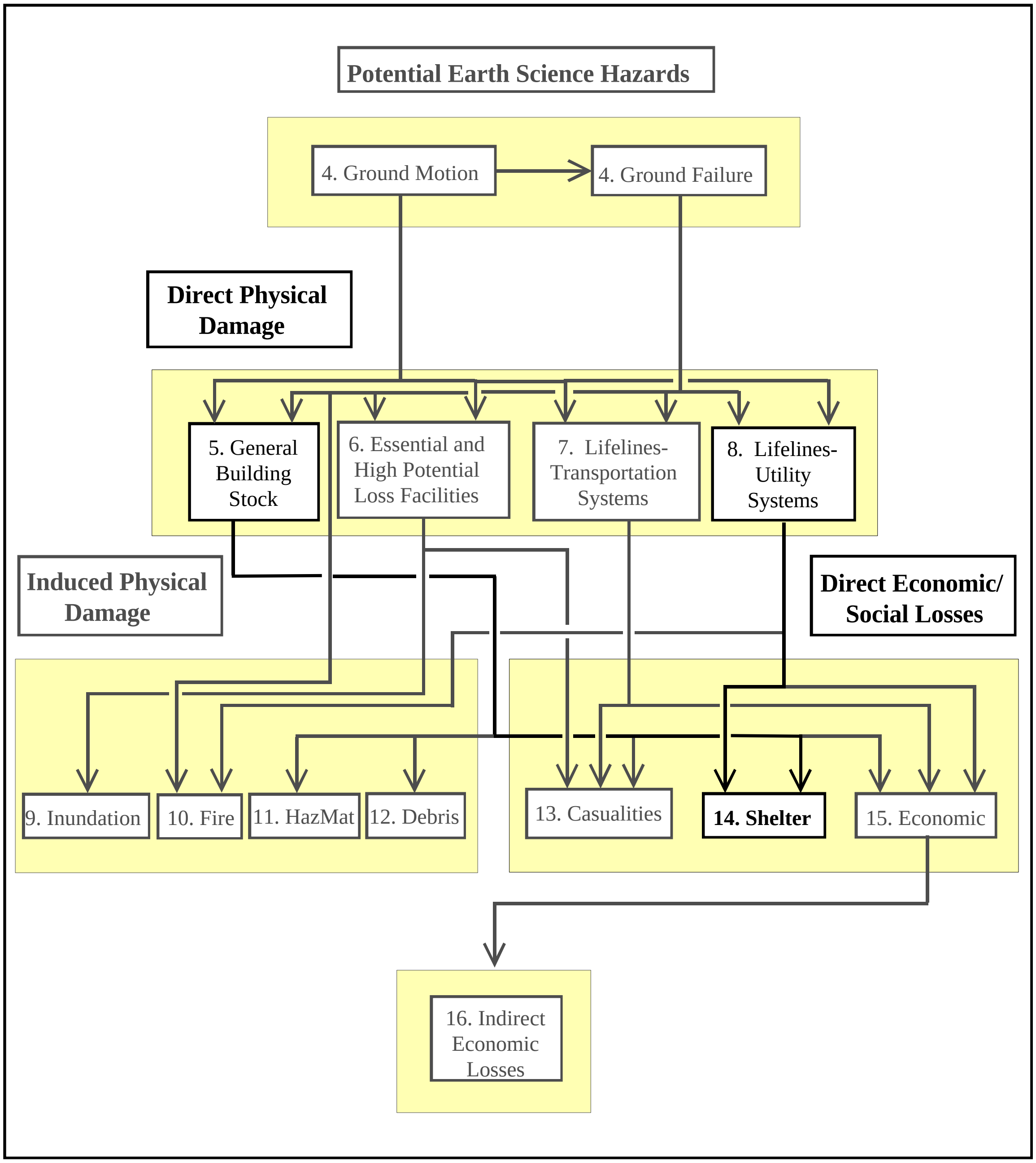
14.1.1 Scope

The shelter model provides two estimates:

- The number of displaced households (due to loss of habitability)
- The number of people requiring only short-term shelter

Loss of habitability is calculated directly from damage to the residential occupancy inventory, and from loss of water and power. The methodology for calculating short-term shelter requirements recognizes that only a portion of those displaced from their homes will seek public shelter, and some will seek shelter even though their residence may have no or insignificant damage.

Households may also be displaced as result of fire following earthquake, inundation (or the threat of inundation) due to dam failure, and by significant hazardous waste releases. This module does not specifically deal with these issues, but an approximate estimate of displacement due to fire or inundation can be obtained by multiplying the residential inventory in affected census tracts by the areas of fire damage or inundation derived from those modules. The hazardous materials module is confined to identifying locations of hazardous materials and no methodology for calculations of damage or loss is provided. If the particular characteristics of the study region give the user cause for concern about the possibility of housing loss from fire, dam failure, or hazardous materials, it would be advisable to initiate specific studies directed towards the problem, as a Level 3 study.



Flowchart 14.1: Direct Social Losses (Displaced Households) Relationship to other Components of the Earthquake Loss Estimation Methodology

14.2 Displaced Households - Form of Loss Estimate

The total number of uninhabitable dwelling units (#UNU) for each census tract of the study region is the output of this portion of the model. In addition, by applying an occupancy rate (households vs. dwelling units), the model converts the habitability data to the number of displaced households. The number of displaced households will be used in Section 14.3 to estimate the short-term shelter needs.

14.2.1 Input Requirements - Displaced Households

The following inputs are required to compute the number of uninhabitable dwelling units and the number of displaced households. The total number of units or households is provided in the default inventory based on census data (Section 3.6.2 of Chapter 3). The user can modify any values based on improved information.

- Total Number of Single-Family Dwelling Units (**#SFU)**
- Total Number of Multi-Family Dwelling Units (**#MFU**)
- Total Number of Households (**#HH**)
- Damage state probability for moderate structural damage in the single-family residential occupancy class (**%SFM**).
- Damage state probability for extensive structural damage state in the single-family residential occupancy class (**%SFE**).
- Damage state probability for complete structural damage state in the single-family residential occupancy class (**%SFC**).
- Damage state probability for moderate structural damage state in the multi- family residential occupancy class (**%MFM**).
- Damage state probability for extensive structural damage state in the multi- family residential occupancy class (**%MFE**).
- Damage state probability for complete structural damage state in the multi- family residential occupancy class (**%MFC**).

  [Note: The probabilities %SFM, %SFE, %SFC, %MFM, %MFE, and %MFC are provided by the Direct Physical Damage Module - Buildings (Chapter 5)].
- Probability that the residential units are without power and/or water (**%WAG**). The data is provided by the Utility System Module or as a user-specified input variable.

14.2.2 Description of Methodology

The estimated number of uninhabitable dwelling units is calculated from the following sources:

- Number of uninhabitable dwelling units due to structural damage (Equation 14-1)
- Number of uninhabitable dwelling units due to loss of utilities (units that would otherwise be habitable) (Equation 14-2)

The number of uninhabitable dwelling units due to structural damage is determined by combining a) the number of uninhabitable dwelling units due to actual structural damage, and b) the number of damaged units that are perceived to be uninhabitable by their occupants. Based on comparisons with previous work (Perkins, 1992; Perkins and Harrald, et. al., unpublished), the methodology considers all dwelling units located in buildings that are in the complete damage state to be uninhabitable. In addition, dwelling units that are in moderately and extensively damaged multi-family structures are also considered to be uninhabitable due to the fact that renters perceive some moderately damaged rental property as uninhabitable. On the other hand, those living in single-family homes are much more likely to tolerate damage and continue to live in their home. Therefore, the total number of uninhabitable units ($\#UNU_{SD}$) due to structural damage is calculated by the following relationship.

$$\begin{aligned}
\%SF &= w_{SFM} \times \%SFM + w_{SFE} \times \%SFE + w_{SFC} \times \%SFC \\
\%MF &= w_{MFM} \times \%MFM + w_{MFE} \times \%MFE + w_{MFC} \times \%MFC \\
\#UNU_{SD} &= \#SFU \times \%SF + \#MFU \times \%MF
\end{aligned} \tag{14-1}$$

The values in Table 14.1 are provided as defaults. Due to the subjective nature of perceptions, users may want to change these values[1].

Table 14.1: Default Values for Damage State Probabilities

Weight Factor	Default Value
w_{SFM}	0.0
w_{SFE}	0.0
w_{SFC}	1.0
w_{MFM}	0.0
w_{MFE}	0.9
w_{MFC}	1.0

In addition to loss of habitable dwelling units due to structural damage, a substantial number of otherwise habitable units can be considered uninhabitable due to loss of water or power. This estimated number of otherwise habitable units that are without power and/or water is determined from inferred lifeline information based on Equation (14-2). In the absence of a lifeline utility analysis, the user can define the value of %WAG.

$$\#UNU_{UTL} = \%WAG \times \left[\#SFU(1 - \%SF) + \#MFU(1 - \%MF)\right] \tag{14-2}$$

[1]For guidance, research has shown a much clearer relationship between the red-, yellow- and green- tagging assigned by building inspectors and perceived habitability than between damage state and perceived habitability (Perkins and Harrald, et al., unpublished). Red- and yellow-tagged multi-family dwellings are considered uninhabitable, while only red-tagged single family homes are considered uninhabitable.

Depending on weather conditions, families living in these units may require only feeding and sources of potable water or may be forced to seek alternative shelter. A cold-weather event will also trigger a higher percentage of those affected by loss of power (heat) leaving their otherwise undamaged homes. Because no data exist on the impact of power losses on perceived habitability, this assessment has been left to the user. The user might pick a percentage of affected households (β) that would be considered displaced households based on, for example, the number of days that the temperature is below a specified level. Alternatively, the user might choose to run two scenarios, one in which 100% of those affected by a power outage needed to seek alternative shelter, and a second in which no one affected sought alternative shelter. The default values assumed for %WAG and β are zero.

By applying an occupancy rate (households vs. dwelling units), the habitability data is converted to the number of displaced households (#DH) using Equation 14-3.

$$\#\text{DH} = \left(\#\text{UNU}_{\text{SD}} + b * \left(\#\text{UNU}_{\text{UTL}}\right)\right)\left(\frac{\#\text{HH}}{\#\text{SFU} + \#\text{MFU}}\right) \tag{14-3}$$

14.3 Short Term Shelter Needs - Form of Loss Estimate

All households living in uninhabitable dwellings will seek alternative shelter. Many will stay with friends and relatives or in the family car. Some will stay in public shelters provided by the Red Cross or others, or rent motel or apartment lodging. This methodology estimates the number of displaced persons seeking public shelter. In addition, observations from past disasters show that approximately 80% of the pre-disaster homeless will seek public shelter. Finally, data from Northridge indicates that approximately one-third of those in public shelters came from residences with little or no structural damage. Depending on the degree to which infrastructure damage is incorporated into #DH, that number of displaced persons could be increased by up to 50% to account for "perceived" structural damage as well as lack of water and power.

14.3.1 Input Requirements - Short-Term Shelter Needs

The inputs required to estimate short-term housing needs are obtained from the displaced household calculations in Section 14.2 and from the default census data. As with the entire methodology, the census data can be modified with improved user information. The inputs listed below are the required census data inputs.

- Number of people in census tract (POP)
- Number of Households (#HH)
- Percentage of households whose income is under \$10,000 (HI_1)
- Percentage of households whose income is \$10,001 to \$15,000 (HI_2)
- Percentage of households whose income is \$15,001 to \$25,000 (HI_3)
- Percentage of households whose income is \$25,001 to \$35,000 (HI_4)

- Percentage of households whose income is over $35,000 ($HI_5$)
- Percentage of white households (HE_1)
- Percentage of black households (HE_2)
- Percentage of Hispanic households (HE_3)
- Percentage of Native American households (HE_4)
- Percentage of Asian households (HE_5)
- Percentage of households owned by householder (HO_1)
- Percentage of households rented by householder (HO_2)
- Percentage of population under 16 years old (HA_1)
- Percentage of population between 16 and 65 years old (HA_2)
- Percentage of population over 65 years old (HA_3)

14.3.2 Description of Methodology

Those seeking public shelter can be estimated from experience in past disasters, including both hurricanes and earthquakes. Those seeking shelter typically have very low incomes, for these families have fewer options. In addition, they tend to have young children or are over 65. Finally, even given similar incomes, Hispanic populations from Central America and Mexico tend to be more concerned about reoccupying buildings than other groups. This tendency appears to be because of the fear of collapsed buildings instilled from past disastrous Latin American earthquakes.

The number of people who require short-term housing can be calculated using the following relationship.

$$\#STP = \sum_{i=1}^{5}\sum_{j=1}^{5}\sum_{k=1}^{2}\sum_{l=1}^{3}\left(\alpha_{ijkl} * \left(\frac{\#DH * POP}{\#HH}\right) * HI_i * HE_j * HO_k * HA_l\right) \tag{14-4}$$

where

#STP	- Number of people requiring short term housing
α_{ijkl}	- is a constant defined by Equation 14-5
HI_i	- Percentage of population in the i^{th} income class
HE_j	- Percentage of population in the j^{th} ethnic class
HO_k	- Percentage of population in the k^{th} ownership class
HA_l	- Percentage of population in the l^{th} age class
POP	- Population in census tract

The value of the α_{ijkl} constant can be calculated using a combination of shelter category "weights" (Table 14.2) (which sum to 1.00) and assigning a relative modification factor (Table 14.3) for each subdivision of each category. In the methodology, default values for the variables for ownership and age are zero.

$$\alpha_{ijkl} = \left(IW * IM_i\right) + \left(EW * EM_j\right) + \left(OW * OM_k\right) + \left(AW * AM_l\right) \tag{14-5}$$

Table 14.2: Shelter Category Weights

Class	Description	Default
IW	Income Weighting Factor	0.73
EW	Ethnic Weighting Factor	0.27
OW	Ownership Weighting Factor	0.00
AW	Age Weighting Factor	0.00

Table 14.3: Shelter Relative Modification Factors

Class	Description	Default
Income		
IM_1	Household Income < $10000	0.62
IM_2	$10000 < Household Income < $15000	0.42
IM_3	$15000 < Household Income < $25000	0.29
IM_4	$25000 < Household Income < $35000	0.22
IM_5	$35000 < Household Income	0.13
Ethnic		
EM_1	White	0.24
EM_2	Black	0.48
EM_3	Hispanic	0.47
EM_4	Asian	0.26
EM_5	Native American	0.26
Ownership		
OM_1	Own Dwelling Unit	0.40
OM_2	Rent Dwelling Unit	0.40
Age		
AM_1	Population Under 16 Years Old	0.40
AM_2	Population Between 16 and 65 Years Old	0.40
AM_3	Population Over 65 Years Old	0.40

Within each of these categories, the default relative modification factors given in Table 14.3 can be used to calculate a_{ijkl} values (i.e., estimate the percentage of each category that will seek shelter) (with an average value for each category being 0.33 to 0.45). These constants were originally developed by George Washington University under contract with the Red Cross and are based on "expert" opinion (Harrald, Fouladi, and Al-Hajj, 1992). Recently collected data from over 200 victims of the Northridge earthquake disaster were analyzed and used in finalizing these constants (Harrald, et. al., 1994). The modification factors provided in Table 14.3 are the mean of the George Washington University modification factors described in these two reports. Data for Native Americans are extremely scarce. Some information from Alaskan disasters indicates that the factor for those seeking shelter is similar for whites and Asians.

14.3.3 User-defined Changes to Weight and Modification Factors

In the methodology, weights can be added which account for age and ownership. As noted in Section 14.3.1, the required population distribution data are available. Remember that the weights must sum to 1.0. Young families tended to seek shelter in a larger proportion than other age groups in Northridge, in part because of lower per capita income. This result is consistent with data from hurricanes. In hurricanes, and Northridge, the elderly populations were also more likely to seek public shelter than average. Use special care if you want to add ownership to ensure that you are not double counting because the multi-family versus single-family issue has already been taken into account when estimating habitability (moderately damaged multi-family units are considered uninhabitable while moderately damaged single family units are considered habitable).

Most recent earthquake disasters and hurricanes have occurred in warm weather areas. A major non-shelter location was the family car and tents in the family's backyard. Should an earthquake occur in a colder climate, more people would probably find these alternate shelters unacceptable. In the methodology, the user is able to adjust the factors specifying the percentage of those displaced that seek public shelter (i.e. the shelter relative modification factors in Table 14.3). When making modifications for weather, be careful not to double count. The adjustment for this module should only take into account the larger percentage of those displaced that will seek public shelter (versus the family car or camping in one's backyard.)

14.3.4 Guidance for Estimates Using Advanced Data and Models

The recent Loma Prieta and Northridge earthquakes in California have not been catastrophic events. Although many people have been displaced in these recent earthquake disasters, the size of the area or the spottiness of the damage have left people with more than minimal incomes the options of alternate shelters.

As noted above, Hispanic populations from areas of Central America and Mexico tended to be more concerned about reoccupying buildings with insignificant or minor damage than other groups because of the fear of collapsed buildings instilled from past disastrous earthquakes in Latin America. Such tendencies will probably expand to all ethnic groups should a large number of casualties occur.

14.4 Guidance for Estimating Long-Term Housing Recovery

Although not calculated by the methodology, the damage to residential units (calculated in the general building stock module) can be combined with relationships between damage and restoration times (in the functional loss module) to estimate the need for longer-term replacement housing. Longer-term needs are accommodated by importing mobile homes, reductions in the vacancy rates, net emigration from an area, and eventual repair or reconstruction of the housing units. Because replacement of permanent housing is subject to normal market and financial forces, low-income housing is the last type of housing to be replaced.

Based on experience in Loma Prieta (Perkins, 1992) and preliminary Northridge analyses (Perkins and Harrald, et. al., unpublished) housing recovery times span a wide range, and are typically far longer than might be estimated from typical planning rules of thumb, and longer than most commercial, industrial and institutional recovery. Housing recovery tends to be very dependent on settlement of insurance claims, federal disaster relief, the effectiveness of the generally smaller contractors who do much residential work, and the financial viability of the home or apartment owner, together with actions taken by state and local governments to expedite the process, and public support of reconstruction (such as the potential desire for historic preservation). The median recovery time figures for residential occupancies shown in Table 15.11 reflect these issues, but there will tend to be very wide variation about the mean. In particular, recovery times for non-wood frame multi-family housing, especially low-income single room occupancy buildings, ought to be measured in years.

14.5 References

Applied Technology Council (ATC), 1991, "Procedures for Postearthquake Safety Evaluation of Buildings **(ATC-20)**". State of California Governor's Office of Emergency Services: Sacramento, CA, 144 pp.

Cuny, F. C., 1975, "Strategies and Approaches for the Provision of Emergency Shelter and Post-Disaster Housing". Intertect: Dallas, Texas.

Dunne, R. G., and Sonnenfeld, P., 1991, "Estimation of Homeless Caseload for Disaster Assistance due to an Earthquake". *SCEPP publication of a 1980 draft document originally prepared for FEMA*: Pasadena, CA.

Harrald, J. R., Abchee, M., Alharthi, H., and Boukari, D., 1991, "The Development of a Methodology for American Red Cross Staffing of a Disaster Under the Federal Response Plan". George Washington Univ. Research Report.

Harrald, J. R., Abchee, M., Cho, S., and Boukari, D., 1990, "Development of a Planning Methodology for Red Cross Catastrophic Earthquake Response". Geo. Wash. Univ. Research Report.

Harrald, J. R., Abchee, M., Cho, S., and Boukari, D., 1990, "An Analysis of the American National Red Cross Staffing for the Hurricane Hugo and the Loma Prieta Earthquake Disaster Relief Operations". Geo. Washington Univ. Research Report.

Harrald, J. R., Abchee, M., Cho, S., and Scholarios, T., 1990, "Analysis of Narrative Reports for Hurricane Hugo and the Loma Prieta Earthquake". Geo. Wash. Univ. Research Report.

Harrald, J. R., Al-Hajj, S., Fouladi, B., and Jeong, D., 1994, "Estimating the Demand for Sheltering in Future Earthquakes". *IEEE Transactions in Engineering Management*, (Publication currently pending).

Harrald, J. R., Fouladi, B., and Al-Hajj, S. F., 1992, "Estimates of Demand for Mass Care Services in Future Earthquakes Affecting the San Francisco Bay Region". Prepared by George Washington University for the American Red Cross Northern California Earthquake Relief and Preparedness Project (NCERPP), 41 pp. plus appendices.

Perkins, J. B., 1992, "Estimates of Uninhabitable Dwelling Units in Future Earthquakes Affecting the San Francisco Bay Region". ABAG: Oakland, California, 89 pp.

Perkins, J.B., Harrald, J.R., and others, unpublished, "Preliminary Results of an NSF-Sponsored Project on Modeling Housing Damage in Earthquakes and Resulting Mass-Care Needs", NSF Grant BCS-9441459.

U.S. Bureau of the Census, May 1991, *Standard Tape File 1 (STF-1A)***.**

U.S. Bureau of the Census, May 1992, *Standard Tape File 3 (STF-3)***.**

Chapter 15
Direct Economic Losses

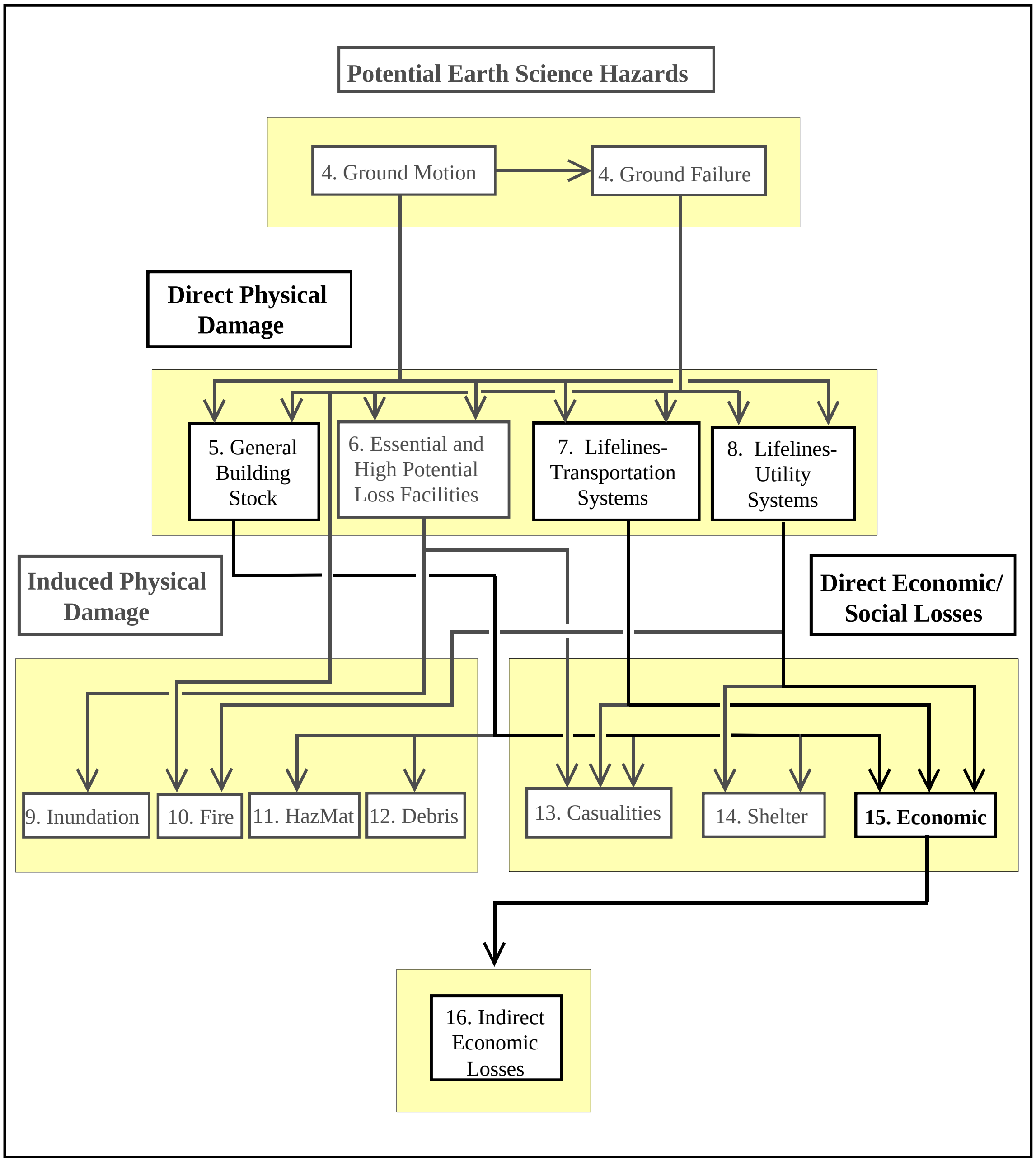
15.1 Introduction

This chapter describes the conversion of damage state information, developed in previous modules, into estimates of dollar loss. In the past, loss estimation studies have generally limited the consideration of loss to estimates of the repair and replacement costs of the building stock.

The methodology provides estimates of the structural and nonstructural repair costs caused by building damage and the associated loss of building contents and business inventory. Building damage can also cause additional losses by restricting the building’s ability to function properly. To account for this, business interruption and rental income losses are estimated. These losses are calculated from the building damage estimates by use of methods described later. The methodology highlighting the Direct Economic Loss component is shown in Flowchart 15.1.

This expression of losses provides an estimate of the costs of building repair and replacement that is a frequently required output of a loss estimation study. The additional estimates of consequential losses give an indication of the immediate impact of such building damage on the community: the financial consequences to the community's businesses due to businesses interruption, the financial resources that will be needed to make good the damage, and an indication of job and housing losses.

In strict economic terms, buildings, inventories, and public facilities represent capital investments that produce income, and the value of the building and inventory will be the capitalized value of the income produced by the investment that created the building or inventory. Hence, if we estimate the dollar value of the buildings damaged or destroyed, and add the income lost from the absence of the functioning facilities we may be overestimating the indirect economic loss (Chapter 16). However, for the assessment of direct economic loss, the losses can be estimated and evaluated independently.



Flowchart 15.1: Direct Economic Losses Relationship to other Components of the Earthquake Loss Estimation Methodology

Since a significant use for loss estimation studies is expected to be that of providing input into future benefit-cost studies used to evaluate mitigation strategies and budgets, the list of these consequential losses is similar to that developed for the FEMA benefit-cost procedure described in FEMA publications 227 and 228, and 255 and 256. This procedure is, however, limited to conventional real-estate parameters similar to those used in evaluating the feasibility of a development project and does not attempt to evaluate the full range of socio/economic impacts that might follow specific mitigation strategies.

Thus, for this loss estimation methodology, even though the derivation of these consequential losses represents a considerable expansion of the normal consideration of building damage/loss, this module is still limited in its consideration of economic loss to those losses that can be directly derived from building and infrastructure damage, and that lend themselves to ready conversion from damage to dollars. The real socio/economic picture is much more complex: economic impacts may have major societal effects on individuals or discrete population groups, and there may be social impacts that ultimately manifest themselves in economic consequences. In many cases the linkages are hard to trace with accuracy and the effects, while easy to discern, are difficult to quantify because definite systematic data is lacking.

For example, the closing of the Oakland/San Francisco Bay Bridge for 30 days following the Loma Prieta earthquake of 1989 required approximately a quarter of a million daily users of the bridge to rearrange their travel patterns. Many individual commuters were forced to take a significantly longer and more costly route to their destinations. At the same time, other commuters changed to use of the BART rail system or bus services, which also altered their family expenditure patterns. More lengthy trips for business service travelers and material suppliers resulted in varying degrees of loss of productivity. Businesses directly related to normal operation of the bridge, such as gas stations and automobile repair shops on the approach routes to the bridge suffered losses.

Repairs to the bridge represented a direct cost to the state budget. At the same time, the revenues from bridge tolls were nonexistent. However, some businesses gained from closure: some gas stations had improved business, and revenues to other bridges, the BART system, and bus companies increased.

Increased commuting time resulted in loss of leisure and family time, and shifts in the customer and sales patterns of many small businesses resulted in an increase in normal business worries.

If this 30-day loss of function had, instead, been a period of years (as is the case for elements of the Bay Area Freeway system) the socio/economic impacts would have been profound and long lasting throughout the Bay region.

This example suggests the range of inter-related consequential impacts stemming from damage to a single structure: but these impacts were accompanied by a host of other impacts to individuals, businesses, institutions and communities that serve further to increase the complexity of post-earthquake effects. As understanding is gained of these interactions, and data collection becomes richer and more systematic, quantification of the consequential losses of earthquake damage can become broader and more accurate.

Given the complexity of the problem and the present paucity of data, the methodology focuses on a few key issues that are of critical importance to government and the community, that can be quantified with reasonable assurance, and that provide a picture of the cost consequences of building and infrastructure damage that are understandable and would be of major concern to a municipality or region. In addition, application of the methodology will provide information that would be useful in a more detailed study of a particular economic or social sector, such as impact on housing stock or on a significant local industry. Finally, the structure of the methodology should be of assistance in future data gathering efforts.

While the links between this module and the previous modules dealing with damage are very direct and the derivations are very transparent, the links between this module and that of Chapter 16, Indirect Economic Losses, are less so. While some of the estimates derived in this module, such as income loss by sector, building repair costs, and the loss of contents and inventories, may be imported directly into the Indirect Loss Module, some interpretation of the direct economic loss estimates would be necessary for a more detailed indirect economic loss study. It would be necessary, for example, to translate the repair and replacement times and costs derived in this module to monthly reconstruction investment estimates for use in a longer-term indirect loss estimate.

15.1.1 Scope

This chapter provides descriptions of the methodologies, the derivation of default data, and explanatory tables for a number of direct economic loss items, derived from estimates of building and lifeline damage. For building related items, methods for calculating the following dollar losses are provided:

- Building Repair and Replacement Costs
- Building Contents Losses
- Building Inventory Losses

To enable time dependent losses to be calculated, default values are provided for:

- Building Recovery Time and Loss of Function (business interruption) time

Procedures for calculating the following time dependent losses are provided:
- Relocation Expenses
- Loss of Proprietors' Income
- Rental Income Losses

For each lifeline, information is provided on replacement values and assumed numerical damage ratios corresponding to damage states. Chapters 7 and 8 provide restoration curves corresponding to lifeline damage states. With this information the cost of damage to lifelines and the elapsed time for their restoration could be calculated; however, no attempt is made to estimate losses due to interruption of customer service, alternative supply services, and the like.

The following lifelines are covered:

Transportation Systems
- Highway Systems
- Railroads
- Light Rail Systems
- Bus Systems
- Port Systems
- Ferry Services
- Airport Systems

Utility Systems:
- Potable Water
- Waste Water
- Oil
- Natural Gas
- Electric Power
- Communication

Dollar losses due to fire and inundation are not explicitly addressed. However, the methodology enables the area of inundation to be estimated and related to the quantity of building stock in the affected census tracts. This, in turn, can be converted into a dollar value.

In a similar manner, a value for building losses from fire can be estimated by relating the area of fire spread to the volume of construction and the construction cost. In both cases, the nature of damage states (which would vary from those of ground shaking damage) are not developed and estimates of dollar loss from these causes should be regarded as very broad estimates. In addition, since the concern is for earthquake-induced fire or inundation, the possibility of double counting of damage is present. More specific studies should be undertaken if the user believes that either fire or inundation might represent a serious risk.

Since the methodology goes no further than indicating sources of hazardous materials, no methodology is provided for estimating losses due to the release of such materials. Again, if the possibility of serious losses from this cause is a matter of concern, specific studies should be undertaken.

15.1.2 Form of Direct Economic Loss Estimates

Direct economic loss estimates are provided in 1994 dollars. In some instances, as in the cost of building replacement, a procedure is provided for the conversion of default dollar values to those prevalent at the time of the loss estimation study. In other instances, user provided information, such as local rental costs, would be provided in current dollar values.

15.1.3 Input Requirements

In general, input data for direct economic losses consists of building damage estimates from the direct physical damage module. The damage estimates are in the form of probabilities of being in each damage state, for each structural type or occupancy class. The building classification system is as discussed in Chapter 3. Damage states are discussed in detail in Chapter 5. Damage state probabilities are provided from the direct physical damage module for both structural and non-structural damage. These damage state probabilities are then converted to monetary losses using inventory information and economic data. For Default Data Analysis values, the buildings are classified into three broad occupancy/use-related categories: residential, commercial/institutional, and industrial. These categories are used to determine the non-structural element make-up of the buildings and the nature and value of their contents. For User-Supplied Data and Advanced Data and Models Analyses, a 28-category occupancy classification (See Table 15.1) is defined that provides for a more refined economic loss analysis. Building replacement cost data is provided for this classification level.

The types of economic data that the user will be expected to supply include repair and replacement costs, contents value for different occupancies, annual gross sales by occupancy, relocation expenses and income by occupancy. While default values are provided for these data, the user may wish to provide more accurate local values or update default values to current dollars.

Direct economic losses for transportation and lifeline systems are limited to the cost of repairing damage to the lifeline system. Default values are provided for replacement values of lifeline components as a guide. It is expected that in a User-Supplied Data Analysis, the user will input replacement values based on knowledge of lifeline values in the region.

Table 15.1: Building Occupancy Classes

No.	Label	Occupancy Class	Description
		Residential	
1	RES1	Single Family Dwelling	Detached House
2	RES2	Mobile Home	Mobile Home
3	RES3	Multi Family Dwelling	Apartment/Condominium
4	RES4	Temporary Lodging	Hotel/Motel
5	RES5	Institutional Dormitory	Group Housing (military, college), Jails
6	RES6	Nursing Home	
		Commercial	
7	COM1	Retail Trade	Store
8	COM2	Wholesale Trade	Warehouse
9	COM3	Personal and Repair Services	Service Station/Shop
10	COM4	Professional/Technical Services	Offices
11	COM5	Banks/Financial Institutions	
12	COM6	Hospital	
13	COM7	Medical Office/Clinic	Offices
14	COM8	Entertainment & Recreation	Restaurants/Bars
15	COM9	Theaters	Theaters
16	COM10	Parking	Garages
		Industrial	
17	IND1	Heavy	Factory
18	IND2	Light	Factory
19	IND3	Food/Drugs/Chemicals	Factory
20	IND4	Metals/Minerals Processing	Factory
21	IND5	High Technology	Factory
22	IND6	Construction	Office
		Agriculture	
23	AGR	Agriculture	
		Religion/Non-Profit	
24	REL	Church	
		Government	
25	GOV1	General Services	Office
26	GOV2	Emergency Response	Police/Fire Station
		Education	
27	ED1	Schools	
28	ED2	Colleges/Universities	Does not include group housing

15.2 Description of Methodology: Buildings

This section describes the estimation of building-related direct economic losses.

15.2.1 Building Repair and Replacement Costs

To establish dollar loss estimates, the damage state probabilities must be converted to dollar loss equivalents. Losses will be due to both structural and non-structural damage. For a given occupancy and damage state, building repair and replacement costs are estimated as the product of the floor area of each building type within the given occupancy, the probability of the building type being in the given damage state, and repair costs of the building type per square foot for the given damage state, summed over all building types within the occupancy.

It can be argued that the true cost of buildings damaged or destroyed is their loss of market value, reflecting the age of the building, depreciation, and the like. Replacement value is a frequently requested output of a loss estimation study, because it gives an immediately understandable picture of the community building losses, and disaster assistance is currently granted on the basis of replacement value. In fact, market value is by no means constant in relation to replacement value. For example, typical estimates of market value include the value of the lot: in locations of high land cost, market value may greatly exceed replacement value (which excludes lot value). Moreover, building age does not necessarily result in a linear loss of market value: after a certain age some buildings begin to acquire additional value by virtue of architectural style and craftsmanship and true replacement cost might greatly exceed market value.

These issues may need to be considered in a detailed evaluation of the direct economic losses where particular building inventories or economic aspects of the damage are being evaluated. Full discussion of these and other related issues may be found in Howe and Cochrane, 1993.

For structural damage, losses are calculated as follows:

$$CS_{ds,i} = CI * \sum_{j=1}^{36} FA_{i,j} * PMBTSTR_{ds,j} * RCS_{ds,i,j} \tag{15-1}$$

$$CS_i = \sum_{ds=2}^{5} CS_{ds,i} \tag{15-2}$$

where:

$CS_{ds,i}$	cost of structural damage (repair and replacement costs) for damage state ds and occupancy i
CS_i	cost of structural damage (repair and replacement costs) for occupancy i
CI	regional cost index multiplier described in Section 15.2.1.2
$FA_{i,j}$	floor area of model building type j in occupancy group i (in square feet), based on the total floor area of occupancy i and the

	distribution of floor area between model building types described in Chapter 3
$PMBTSTR_{ds,j}$	probability of model building type j being in structural damage state ds, see Chapter 5
$RCS_{ds,i,j}$	structural repair and replacement costs (per square foot) for occupancy i and model building type j in damage state ds, Tables 15.2a through 15.2d

The structural repair cost per square foot for structural damage for each damage state, occupancy, and structural system type is shown in Tables 15.2a through 15.2d. The repair costs for model building types within a structural system type are all the same (e.g. model building types S2L, S2M, and S2H all have the same repair costs listed under structural system type heading S2 in Tables 15.2a through 15.2d). Note that damage state "none" (ds = 1) does not contribute to the calculation of the cost of structural damage and thus the summation in Equation 15-2 is from ds = 2 to ds = 5.

A similar calculation is performed for non-structural damage. Non-structural damage is broken down into acceleration sensitive damage (damage to ceilings, equipment that is an integral part of the facility such as mechanical and electrical equipment, piping and elevators) and drift sensitive damage (partitions, exterior walls, ornamentation and glass). Non-structural damage does not include the damage to contents such as furniture and computers that is accounted for in Section 15.2.2. Non-structural damage costs are calculated as follows:

$$CNSA_{ds,i} = CI*FA_i*PONSA_{ds,i}*RCA_{ds,} \qquad (15\text{-}3)$$

$$CNSA_i = \sum_{ds=2}^{5} CNSA_{ds,i} \qquad (15\text{-}4)$$

$$CNSD_{ds,i} = CI*FA_i*PONSD_{ds,i}*RCD_{ds,i} \qquad (15\text{-}5)$$

$$CNSD_i = \sum_{ds=2}^{5} CNSD_{ds,i} \qquad (15\text{-}6)$$

where:

$CNSA_{ds,i}$	cost of acceleration-sensitive non-structural damage (repair and replacement costs) for damage state ds and occupancy i
$CNSA_i$	cost of acceleration-sensitive non-structural damage (repair and replacement costs) for occupancy i
$CNSD_{ds,i}$	cost of drift-sensitive non-structural damage (repair and replacement costs) for damage state ds and occupancy i
$CNSD_i$	cost of drift-sensitive non-structural damage (repair and replacement costs) for occupancy i
CI	regional cost index multiplier described in Section 15.2.1.2

FA_i	floor area of occupancy group i (in square feet)
$PONSA_{ds,i}$	probability of occupancy i being in non-structural acceleration sensitive damage state ds, see Chapter 5
$PONSD_{ds,i}$	probability of occupancy i being in non-structural drift sensitive damage state ds, see Chapter 5
$RCA_{ds,i}$	acceleration sensitive non-structural repair and replacement costs (per square foot) for occupancy i in damage state ds (Table 15-3)
$RCD_{ds,i}$	drift sensitive non-structural repair and replacement costs (per square foot) for occupancy i in damage state ds (Table 15-4)

The cost per square foot for non-structural damage for each damage state are shown in Tables 15.3 and 15.4 for acceleration and drift sensitive non-structural components, respectively.

To determine the total cost of non-structural damage for occupancy class i (CNS_i), Equations 15-4 and 15-6 must be summed.

$$CNS_i = CNSA_i + CNSD_i \tag{15-7}$$

The total cost of building damage (CBD_i) for occupancy class i is the sum of the structural and non-structural damage.

$$CBD_i = CS_i + CNS_i \tag{15-8}$$

Finally, to determine the total cost of building damage (CBD), Equation 15-8 must be summed over all occupancy classes.

$$CBD = \sum_i CBD_i \tag{15-9}$$

15.2.1.1 Default Values for Building Repair Costs

Tables 15.2a through 15.2d show the default values for the repair costs related to the 28 occupancy classifications. These values must be adjusted to reflect different building costs related to location. These adjustment factors are discussed in Section 15.2.1.2. The relative percentage of total building cost allocated to structural and non-structural components is derived from the *Means* component breakdowns for each model building. See Tables 15C.1 and 15C.2 of Appendix 15C.

Tables 15.3 and 15.4 show the default values for the costs of repair of acceleration-sensitive and drift sensitive components. Acceleration sensitive non-structural components include hung ceilings, mechanical and electrical equipment, and elevators. Drift sensitive components include partitions, exterior wall panels, and glazing. Based on the component breakdown provided in *Means* the relative percentages of drift and acceleration sensitive components, (aggregated and numbers rounded off) are estimated as follows:

Occupancy	Acceleration sensitive components	Drift sensitive components
Single Family residential	35%	65%
Other residential	50%	50%
Commercial	60%	40%
Industrial	85%	15%
Agriculture	85%	15%
Religion	60%	40%
Government	60%	40%
Education	35%	65%

The cost of damage is expressed as a percentage of the complete damage state. The assumed relationship between damage states and repair/replacement costs, for both structural and non-structural components, is as follows:

Slight damage:	2% of complete
Moderate damage:	10% of complete
Extensive damage:	50% of complete

These values are consistent with and in the range of the damage definitions and corresponding damage ratios presented in *ATC-13 Earthquake Damage Evaluation Data for California*. For specific building inventories, at an Advanced Data and Models Analysis, more precise estimates of structural/non-structural quantity and cost relationships could be obtained by the user.

Table 15.2a: Structural Repair Costs for Complete Damage (Dollars Per Square Foot)

	Structural System Type															
Occupancy	W1	W2	S1	S2	S3	S4	S5	C1	C2	C3	PC1	PC2	RM1	RM2	URM	MH
RES1	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	*
RES2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	11
RES3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	*
RES4	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
RES5	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
RES6	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
COM1	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
COM2	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
COM3	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11
COM4	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
COM5	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16	16
COM6	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
COM7	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13
COM8	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
COM9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
COM10	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
IND1	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
IND2	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
IND3	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
IND4	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
IND5	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
IND6	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
AGR1	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
REL1	17	17	17	17	17	17	17	17	17	17	0	17	17	17	17	17
GOV1	12	12	12	12	12	12	12	12	12	12	0	12	12	12	12	12
GOV2	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17	17
EDU1	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14
EDU2	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11	11

Table 15.2b: Structural Repair Costs for Extensive Damage (Dollars Per Square Foot)

	Structural System Type															
Occupancy	W1	W2	S1	S2	S3	S4	S5	C1	C2	C3	PC1	PC2	RM1	RM2	URM	MH
RES1	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	4.5	4.5	*
RES2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	3.3
RES3	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	3.3	3.3	*
RES4	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	3.3	3.3	3.3
RES5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	4.5	4.5	4.5
RES6	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	4.2	4.2	4.2
COM1	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	4.5	4.5	4.5
COM2	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	3.3	3.3	3.3
COM3	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	3.3	3.3	3.3
COM4	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	4.2	4.2	4.2
COM5	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	8.0	4.8	4.8	4.8
COM6	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	5.1	5.1	5.1
COM7	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	6.5	3.9	3.9	3.9
COM8	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	3.0	3.0	3.0
COM9	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	2.7	2.7	2.7
COM10	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	4.2	4.2	4.2
IND1	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
IND2	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
IND3	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
IND4	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
IND5	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
IND6	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	2.4	2.4	2.4
AGR1	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	1.8	1.8	1.8
REL1	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	0.0	8.5	8.5	5.1	5.1	5.1
GOV1	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	6.0	0.0	6.0	6.0	3.6	3.6	3.6
GOV2	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	5.1	5.1	5.1
EDU1	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	7.0	4.2	4.2	4.2
EDU2	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	5.5	3.3	3.3	3.3

Table 15.2c: Structural Repair Costs for Moderate Damage (Dollars Per Square Foot)

	Structural System Type															
Occupancy	W1	W2	S1	S2	S3	S4	S5	C1	C2	C3	PC1	PC2	RM1	RM2	URM	MH
RES1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	*
RES2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	1.1
RES3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	*
RES4	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
RES5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
RES6	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
COM1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
COM2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
COM3	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
COM4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
COM5	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
COM6	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
COM7	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3
COM8	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
COM9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
COM10	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
IND1	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IND2	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IND3	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IND4	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IND5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
IND6	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
AGR1	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
REL1	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	*	1.7	1.7	1.7	1.7	1.7
GOV1	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	*	1.2	1.2	1.2	1.2	1.2
GOV2	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
EDU1	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.4
EDU2	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1

Table 15.2d: Structural Repair Costs for Slight Damage (Dollars Per Square Foot)

	Structural System Type															
Occupancy	W1	W2	S1	S2	S3	S4	S5	C1	C2	C3	PC1	PC2	RM1	RM2	URM	MH
RES1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	*
RES2	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	0.2
RES3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	*
RES4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
RES5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
RES6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
COM3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
COM4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM5	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM6	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM7	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
COM8	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
COM9	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
COM10	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
IND1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IND2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IND3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IND4	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IND5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
IND6	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
AGR1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
REL1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	*	0.3	0.3	0.3	0.3	0.3
GOV1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	*	0.2	0.2	0.2	0.2	0.2
GOV2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
EDU1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
EDU2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2

Table 15.3: Acceleration Sensitive Non-structural Repair Costs (Dollars Per Square Foot)

No.	Label	Occupancy Class	Acceleration Sensitive Non-structural Damage State			
			Slight	Moderate	Extensive	Complete
		Residential				
1	RES1	Single Family Dwelling	0.3	1.7	5.1	17
2	RES2	Mobile Home	0.3	1.7	5.1	17
3	RES3	Multi Family Dwelling	0.7	3.5	10.5	35
4	RES4	Temporary Lodging	0.7	3.5	10.5	35
5	RES5	Institutional Dormitory	0.7	3.3	9.9	33
6	RES6	Nursing Home	0.6	3.1	9.3	31
		Commercial				
7	COM1	Retail Trade	0.4	2.2	6.6	22
8	COM2	Wholesale Trade	0.3	1.4	4.2	14
9	COM3	Personal and Repair Services	0.7	3.4	10.2	34
10	COM4	Professional/Technical/ Business Services	0.7	3.5	10.5	35
11	COM5	Banks/Financial Institutions	1.2	6.0	18.0	60
12	COM6	Hospital	1.2	6.2	18.6	62
13	COM7	Medical Office/Clinic	0.9	4.6	13.8	46
14	COM8	Entertainment & Recreation	1.1	5.5	16.5	55
15	COM9	Theaters	0.8	3.9	11.7	39
16	COM10	Parking	0.1	0.5	1.5	5
		Industrial				
17	IND1	Heavy	0.7	3.7	11.1	37
18	IND2	Light	0.7	3.7	11.1	37
19	IND3	Food/Drugs/Chemicals	0.7	3.7	11.1	37
20	IND4	Metals/Minerals Processing	0.7	3.7	11.1	37
21	IND5	High Technology	0.7	3.7	11.1	37
22	IND6	Construction	0.7	3.7	11.1	37
		Agriculture				
23	AGR1	Agriculture	0.1	0.6	1.8	6
		Religion/Non-Profit				
24	REL1	Church/Membership Organization	0.8	4.1	12.3	41
		Government				
25	GOV1	General Services	0.7	3.3	9.9	33
26	GOV2	Emergency Response	1.1	5.6	16.8	56
		Education				
27	EDU1	Schools/Libraries	0.5	2.4	7.2	24
28	EDU2	Colleges/Universities	0.6	2.9	8.7	29

Table 15.4: Drift Sensitive Non-structural Repair Costs (Dollars Per Square Foot)

No.	Label	Occupancy Class	Drift Sensitive Non-structural Damage State			
			Slight	Moderate	Extensive	Complete
		Residential				
1	RES1	Single Family Dwelling	0.6	3.2	16.0	32.0
2	RES2	Mobile Home	0.3	1.7	8.5	17.0
3	RES3	Multi Family Dwelling	0.7	3.4	17.0	34.0
4	RES4	Temporary Lodging	0.7	3.5	17.5	35.0
5	RES5	Institutional Dormitory	0.6	3.2	16.0	32.0
6	RES6	Nursing Home	0.6	3.1	15.5	31.0
		Commercial				
7	COM1	Retail Trade	0.3	1.4	7.0	14.0
8	COM2	Wholesale Trade	0.2	0.9	4.5	9.0
9	COM3	Personal and Repair Services	0.5	2.3	11.5	23.0
10	COM4	Professional/Technical/ Business Services	0.5	2.4	12.0	24.0
11	COM5	Banks/Financial Institutions	0.8	4.0	20.0	40.0
12	COM6	Hospital	0.8	4.2	21.0	42.0
13	COM7	Medical Office/Clinic	0.6	3.1	15.5	31.0
14	COM8	Entertainment & Recreation	0.7	3.6	18.0	36.0
15	COM9	Theaters	0.5	2.6	13.0	26.0
16	COM10	Parking	0.1	0.4	2.0	4.0
		Industrial				
17	IND1	Heavy	0.1	0.6	3.0	6.0
18	IND2	Light	0.1	0.6	3.0	6.0
19	IND3	Food/Drugs/Chemicals	0.1	0.6	3.0	6.0
20	IND4	Metals/Minerals Processing	0.1	0.6	3.0	6.0
21	IND5	High Technology	0.1	0.6	3.0	6.0
22	IND6	Construction	0.1	0.6	3.0	6.0
		Agriculture				
23	AGR1	Agriculture	*	0.1	0.5	1
		Religion/Non-Profit				
24	REL1	Church/Membership Organization	0.6	2.8	14	28
		Government				
25	GOV1	General Services	0.4	2.2	11	22
26	GOV2	Emergency Response	0.8	3.8	19	38
		Education				
27	EDU1	Schools/Libraries	0.7	3.6	18	36
28	EDU2	Colleges/Universities	1.2	6.0	30	60

Note that the costs in Table 15.2a and in the last column of Tables 15.3 and 15.4 correspond to replacement costs, since the complete damage state implies that the structure must be replaced. The replacement value of the structure is the sum of the structural and non-structural components. Thus to determine total replacement cost per square foot for a particular occupancy, one must sum values from Tables 15.2a, 15.3 and 15.4 as follows:

$$RC_i = CI*[RCA_{5,i} + RCD_{5,i} + RCS_{5,i}] \tag{15-10}$$

$$RCS_{5,i} = \sum_{j=1}^{36} RCMBT_{5,i,j}*FA_{i,j}/FA_i$$

where:

RC_i	replacement costs (per square foot) for occupancy i
CI	regional cost index multiplier described in Section 15.2.1.2
$RCA_{5,i}$	acceleration sensitive non-structural repair (per square foot) for occupancy i in damage state 5
$RCD_{5,i}$	drift sensitive non-structural repair (per square foot) for occupancy i in damage state 5
$RCS_{5,i}$	structural repair costs (per square foot) for occupancy i in damage state 5
$RCMBT_{5,i,j}$	structural replacement cost for model building type j in occupancy i in damage state 5
$FA_{i,j}$	floor area of model building type j in occupancy group i (in square feet), see Equation 15-1
FA_i	floor area of occupancy group i (in square feet)

The replacement costs (damage state = complete) shown in Tables 15.2a, 15.3, and 15.4 are derived from Means Square Foot Costs 1994, for Residential, Commercial, Industrial, and Institutional buildings. The Means publication is a nationally accepted reference on building construction costs, which is published annually. This publication provides cost information for a number of low-rise residential model buildings, and for 70 other residential, commercial, institutional and industrial buildings. These are presented in a format that shows typical costs for each model building, showing variations by size of building, type of building structure, and building enclosure. One of these variations is chosen as "typical” for this model, and a breakdown is provided that shows the cost and percentages of each building system or component. From this breakdown it is possible to determine the relative value of structural and non-structural components for each model building. In addition, for each model building, the spread of costs from the database is provided.

For example, the model building representing a 5-10 story office building is an 8-story building with 100,000 square feet of floor area. The typical square foot cost is

$67.80/square foot, based on a steel frame structure with precast concrete panel exterior. The cost related to building area varies from $73.90/square foot for a 50,000 square foot building to $66.15/square foot for a building of 130,000 square feet. Depending on the exterior cladding, the cost varies from $67.80/square foot to $74.85/square foot. A range of completed project costs from $41.15 to $116.85 per square foot have been reported for this type of structure depending on design alternatives, owners requirements, and geographical location.

The Means typical costs omit site work costs, but include 15% contractors overhead and profit, and a cost for the architect's fee that varies from 6 % to 11 % of construction cost according to occupancy type. In addition, an **additional 15% has been added** to the Means costs to reflect cost of financing, decision-making delays and additional construction services such as repair and/or demolition. Finally, in view of the generic nature of this analysis, the Means square foot costs have been rounded to the nearest dollar.

For the loss estimation methodology, selected Means models have been chosen from the 70 plus models that represent the 28 occupancy types. The wide range of costs shown, even for a single model, emphasize the importance of understanding that the dollar values shown should only be used to represent costs of large aggregations of building types. If costs for single buildings or small groups (such as a college campus) are desired for more detailed loss analysis, then local building specific cost estimates should be used.

The Means model buildings are classified by occupancy. It is clear from the cost breakdowns that cost variations relate much more to occupancy than to material or structural system type.

Since Means is published annually, fluctuations in typical building cost can be tracked and the user can insert the most up-to-date Means typical building cost into the default database. This procedure is outlined in Section 15.2.1.3.

15.2.1.2 Default Values for Regional Cost Variation

Construction costs vary significantly from one location to another. In order to account for this, the methodology provides default values for multipliers to be applied to the typical costs provided in Tables 15.2 through 15.4, which are based on National averages for materials and installation. These multipliers are shown in the Means Square Foot Cost publication as *Historical Cost Indices.* Means provides indices for a number of cities in each state (some of the smaller states have one or two cities only). This information, along with expert opinion, was used to develop default regional cost modifiers for each state in the United States. Since certain counties in each state can vary drastically from the statewide average (e.g. California = 116.9 versus San Francisco = 132.7), county exceptions are provided for a limited number of counties. The default values for regional cost variation are presented in Appendix 15A, Table 15A.1.

In calculating losses, values in Tables 15.2a through 15.4 are multiplied by the local index/100. For example, for buildings located in Boston (see Table 15A.1), values in Tables 15.2a through 15.4 are multiplied by 1.256.

15.2.1.3 Procedure for Updating Building Cost Estimates

The typical costs shown in Tables 15.2 through 15.4 are for 1994. The historical cost indices provided in the Means publication can also be used to adjust costs (generally upwards) to the year in which the loss estimate is being implemented. (It will be necessary for the user to obtain access to the Means publication for the year of implementation.)

Means provides cost indices, for the 200 representative cities, for the last 54 years (i.e. 1994 to 1940). These are updated each year, so the difference in index for a given city relative to 1994 can be ascertained from the list and the user can adjust the default value, if the difference is judged to be significant.

15.2.2 Building Contents Losses

Building contents are defined as furniture, equipment that is not integral with the structure, computers and other supplies. Contents do not include inventory or non-structural components (see Section 15.2.1) such as lighting, ceilings, mechanical and electrical equipment and other fixtures. It is assumed that most contents damage, such as overturned cabinets and equipment or equipment sliding off tables and counters, is a function of building accelerations. Therefore, acceleration sensitive non-structural damage is considered to be a good indicator of contents damage. That is, if there is no acceleration sensitive non-structural damage, it is unlikely that there will be contents damage. The cost of contents damage is calculated as follows:

$$CCD_i = CI*CV_i*\sum_{ds=2}^{5} CD_{ds,i}*RC_{ds,i} \qquad (15\text{-}11)$$

$$RC_{ds,i} = \sum_{j=1}^{36} PMBTNSA_{ds,j}*FA_{i,j}*(RCA_{5,i}+RCD_{5,i}+RCMBT_{5,i,j})$$

where:

CCD_i	cost of contents damage for occupancy i
CI	regional cost index multiplier described in Section 15.2.1.2
CV_i	contents value for occupancy i (expressed as percent of replacement value, see Table 15.5)
$CD_{ds,i}$	percent contents damage for occupancy i in damage state ds (from Table 15.6)
$RC_{ds,i}$	replacement costs (dollars) for occupancy i in damage state ds

$PMBTNSA_{ds,j}$	the probability of model building type j being in non-structural acceleration sensitive damage state ds, see Chapter 5
$FA_{i,j}$	floor area of model building type j in occupancy group i (in square feet), see Equation 15-1
$RCA_{5,i}$	acceleration sensitive non-structural repair (per square foot) for occupancy i in damage state 5, Table 15.3
$RCD_{5,i}$	drift sensitive non-structural repair (per square foot) for occupancy i in damage state 5, Table 15.4
$RCMBT_{5,i,j}$	structural repair cost (per square foot) for model building type j in occupancy 5 in damage state 5, Table 15.2a

Table 15.5 provides default contents values for each occupancy as a percentage of the replacement value of the facility. This table is based on values found in Table 4.11 of ATC-13 [ATC, 1985]. The contents damage percentages in Table 15.6 assume that at complete damage state some percentage of contents, set at 15%, can be retrieved. At the present time, contents damage percentages in Table 15.6 are the same for all occupancies.

Table 15.5: Contents Value as Percentage of Building Replacement Value (from Table 4.11 of ATC-13, 1985)

No.	Label	Occupancy Class	Contents Value (%)
		Residential	
1	RES1	Single Family Dwelling	50
2	RES2	Mobile Home	50
3	RES3	Multi Family Dwelling	50
4	RES4	Temporary Lodging	50
5	RES5	Institutional Dormitory	50
6	RES6	Nursing Home	50
		Commercial	
7	COM1	Retail Trade	100
8	COM2	Wholesale Trade	100
9	COM3	Personal and Repair Services	100
10	COM4	Professional/Technical/ Business Services	100
11	COM5	Banks	100
12	COM6	Hospital	150
13	COM7	Medical Office/Clinic	150
14	COM8	Entertainment & Recreation	100
15	COM9	Theaters	100
16	COM10	Parking	50
		Industrial	
17	IND1	Heavy	150
18	IND2	Light	150
19	IND3	Food/Drugs/Chemicals	150
20	IND4	Metals/Minerals Processing	150
21	IND5	High Technology	150
22	IND6	Construction	100
		Agriculture	
23	AGR1	Agriculture	100
		Religion/Non/Profit	
24	REL1	Church/Membership Organization	100
		Government	
25	GOV1	General Services	100
26	GOV2	Emergency Response	150
		Education	
27	EDU1	Schools/Libraries	100
28	EDU2	Colleges/Universities	150

Table 15.6: Percent Contents Damage

No.	Label	Occupancy Class	Acceleration Sensitive Non-structural Damage State			
			Slight	Moderate	Extensive	Complete*
		Residential				
1	RES1	Single Family Dwelling	1	5	25	50
2	RES2	Mobile Home	1	5	25	50
3	RES3	Multi Family Dwelling	1	5	25	50
4	RES4	Temporary Lodging	1	5	25	50
5	RES5	Institutional Dormitory	1	5	25	50
6	RES6	Nursing Home	1	5	25	50
		Commercial				
7	COM1	Retail Trade	1	5	25	50
8	COM2	Wholesale Trade	1	5	25	50
9	COM3	Personal and Repair Services	1	5	25	50
10	COM4	Professional/Technical/ Business Services	1	5	25	50
11	COM5	Banks/Financial Institutions	1	5	25	50
12	COM6	Hospital	1	5	25	50
13	COM7	Medical Office/Clinic	1	5	25	50
14	COM8	Entertainment & Recreation	1	5	25	50
15	COM9	Theaters	1	5	25	50
16	COM10	Parking	1	5	25	50
		Industrial				
17	IND1	Heavy	1	5	25	50
18	IND2	Light	1	5	25	50
19	IND3	Food/Drugs/Chemicals	1	5	25	50
20	IND4	Metals/Minerals Processing	1	5	25	50
21	IND5	High Technology	1	5	25	50
22	IND6	Construction	1	5	25	50
		Agriculture				
23	AGR1	Agriculture	1	5	25	50
		Religion/Non-Profit				
24	REL1	Church/Membership Organization	1	5	25	50
		Government				
25	GOV1	General Services	1	5	25	50
26	GOV2	Emergency Response	1	5	25	50
		Education				
27	EDU1	Schools/Libraries	1	5	25	50
28	EDU2	Colleges/Universities	1	5	25	50

*At complete damage state, it is assumed that some salvage of contents will take place.

15.2.3 Business Inventory Losses

Business inventories vary considerably with occupancy. For example, the value of inventory for a high tech manufacturing facility would be very different from that of a retail store. Thus, it is assumed for this model that business inventory for each occupancy class is based on annual sales. Since losses to business inventory most likely occur from stacks of inventory falling over, objects falling off shelves, or from water damage when piping breaks, it is assumed, as it was with building contents, that acceleration sensitive non-structural damage is a good indicator of losses to business inventory. Business inventory losses then become the product of the total inventory value (floor area times the percent of gross sales or production per square foot) of buildings of a given occupancy in a given acceleration-sensitive damage state, the percent loss to the inventory and the probability of given damage states. The business inventory losses are given by the following expressions.

$$INV_i = FA_i * SALES_i * BI_i * \sum_{ds=2}^{5} PONSA_{ds,i} * INVD_{ds,i} \quad (15\text{-}12)$$

$$INV = INV_7 + INV_8 + \sum_{i=17}^{23} INV_i \quad (15\text{-}13)$$

where:

INV_i	value of inventory losses for occupancy i
INV	total value of inventory losses
FA_i	floor area of occupancy group i (in square feet)
$SALES_i$	annual gross sales or production (per square foot) for occupancy i (see Table 15.7)
BI_i	business inventory as a percentage of annual gross sales for occupancy i (i = 7, 8, 17-23, see Table 15.8)
$PONSA_{ds,i}$	probability of occupancy i being in non-structural acceleration sensitive damage state ds, see Chapter 5
$INVD_{ds,i}$	percent inventory damage for occupancy i in damage state ds (from Table 15.9)

Statistics representing national or state economic sectors may not adequately reflect the regional situation. Therefore, estimates of annual gross sales or the value of production for any one of the 28 economic sectors can vary widely depending on the type of firms that are located in the region. It is important to review and adjust any data to insure that the regional economy is correctly portrayed. Annual sales or production per square foot of building can be estimated by dividing the output-employment ratio (sector output/sector employment) by the average floor space occupied by employee. Current data to derive the regional (county or standard metropolitan statistical area), sector output-employment ratio is usually available from either the state or the U.S. Department of Commerce's Bureau of Economic Analysis [(202) 482-1986]. The annual sales per square foot for the agriculture category are for greenhouses. The average sector floor space occupied per employee is based on values found in ATC-13, table 4.7 (pages 94-97). Judgment was used in estimating of business inventory as a percent of gross annual sales.

Table 15.7: Annual Gross Sales or Production (Dollars per Square Foot)

No.	Label	Occupancy Class	1990 Output/ Employment*	Sq. ft. floor Space/Employee**	Annual Sales ($/ft^2)
		Commercial			
7	COM1	Retail Trade	$24,979	825	30
8	COM2	Wholesale Trade	$38,338	900	43
		Industrial			
17	IND1	Heavy	$220,212	550	400
18	IND2	Light	$74,930	590	127
19	IND3	Food/Drugs/Chemicals	$210,943	540	391
20	IND4	Metals/Minerals Processing	$268,385	730	368
21	IND5	High Technology	$73,517	300	245
22	IND6	Construction	$107,739	250	431
		Agriculture			
23	AGR1	Agriculture	$20,771	250	83

* Typical sector values.
** ATC-13, Table 4.7, pages 94-97 (ATC, 1985).

Table 15.8: Business Inventory (% of Gross Annual Sales)

No.	Label	Occupancy Class	Business Inventory (%)
		Commercial	
7	COM1	Retail Trade	13
8	COM2	Wholesale Trade	10
		Industrial	
17	IND1	Heavy	5
18	IND2	Light	4
19	IND3	Food/Drugs/Chemicals	5
20	IND4	Metals/Minerals Processing	3
21	IND5	High Technology	4
22	IND6	Construction	2
		Agriculture	
23	AGR1	Agriculture	8

Table 15.9: Percent Business Inventory Damage

No.	Label	Occupancy Class	Acceleration Sensitive Non-structural Damage State			
			Slight	Moderate	Extensive	Complete*
		Commercial				
7	COM1	Retail Trade	1	5	25	50
8	COM2	Wholesale Trade	1	5	25	50
		Industrial				
17	IND1	Heavy	1	5	25	50
18	IND2	Light	1	5	25	50
19	IND3	Food/Drugs/Chemicals	1	5	25	50
20	IND4	Metals/Minerals Processing	1	5	25	50
21	IND5	High Technology	1	5	25	50
22	IND6	Construction	1	5	25	50
		Agriculture				
23	AGR1	Agriculture	1	5	25	50

*At complete damage state, it is assumed that some salvage of inventory will take place.

15.2.4 Building Repair Time/Loss of Function

The damage state descriptions provide a basis for establishing loss of function and repair time. A distinction should be made between loss of function and repair time. Here loss of function is the time that a facility is not capable of conducting business. This, in general, will be shorter than repair time because business will rent alternative space while repairs and construction are being completed. The time to repair a damaged building can be divided into two parts: construction and clean-up time, and time to obtain financing, permits and complete design. For the lower damage states, the construction time will be close to the real repair time. At the higher damage levels, a number of additional tasks must be undertaken that typically will considerably increase the actual repair time. These tasks, which may vary considerably in scope and time between individual projects, include:

- Decision-making (related to business of institutional constraints, plans, financial status, etc.)
- Negotiation with FEMA (for public and non-profit), SBA etc.
- Negotiation with insurance company, if insured
- Obtain financing
- Contract negotiation with design firms(s)
- Detailed inspections and recommendations
- Preparation of contract documents
- Obtain building and other permits
- Bid/negotiate construction contract
- Start-up and occupancy activities after construction completion

Building repair and clean-up times are presented in Table 15.10. These times represent estimates of the median time for actual cleanup and repair, or construction. These estimates are extended in Table 15.11 to account for delays in decision-making, financing, inspection etc., as outlined above, and represent estimates of the median time for recovery of building functions.

Table 15.10: Building Cleanup and Repair Time (Construction) (Time in Days)

No.	Label	Occupancy Class	Construction Time				
			Structural Damage State				
			None	Slight	Moderate	Extensive	Complete
		Residential					
1	RES1	Single Family Dwelling	0	2	30	90	180
2	RES2	Mobile Home	0	2	10	30	60
3	RES3	Multi Family Dwelling	0	5	30	120	240
4	RES4	Temporary Lodging	0	5	30	120	240
5	RES5	Institutional Dormitory	0	5	30	120	240
6	RES6	Nursing Home	0	5	30	120	240
		Commercial					
7	COM1	Retail Trade	0	5	30	90	180
8	COM2	Wholesale Trade	0	5	30	90	180
9	COM3	Personal and Repair Services	0	5	30	90	180
10	COM4	Professional/Technical/ Business Services	0	5	30	120	240
11	COM5	Banks/Financial Institutions	0	5	30	90	180
12	COM6	Hospital	0	10	45	180	360
13	COM7	Medical Office/Clinic	0	10	45	180	240
14	COM8	Entertainment & Recreation	0	5	30	90	180
15	COM9	Theaters	0	5	30	120	240
16	COM10	Parking	0	2	20	80	160
		Industrial					
17	IND1	Heavy	0	10	30	120	240
18	IND2	Light	0	10	30	120	240
19	IND3	Food/Drugs/Chemicals	0	10	30	120	240
20	IND4	Metals/Minerals Processing	0	10	30	120	240
21	IND5	High Technology	0	20	45	180	360
22	IND6	Construction	0	5	20	80	160
		Agriculture					
23	AGR1	Agriculture	0	2	10	30	60
		Religion/Non-Profit					
24	REL1	Church/Membership Organization	0	10	30	120	240
		Government					
25	GOV1	General Services	0	10	30	120	240
26	GOV2	Emergency Response	0	5	20	90	180
		Education					
27	EDU1	Schools/Libraries	0	10	30	120	240
28	EDU2	Colleges/Universities	0	10	45	180	360

Table 15.11: Building Recovery Time
(Time in Days)

No.	Label	Occupancy Class	Recovery Time				
			Structural Damage State				
			None	Slight	Moderate	Extensive	Complete
		Residential					
1	RES1	Single Family Dwelling	0	5	120	360	720
2	RES2	Mobile Home	0	5	20	120	240
3	RES3	Multi Family Dwelling	0	10	120	480	960
4	RES4	Temporary Lodging	0	10	90	360	480
5	RES5	Institutional Dormitory	0	10	90	360	480
6	RES6	Nursing Home	0	10	120	480	960
		Commercial					
7	COM1	Retail Trade	0	10	90	270	360
8	COM2	Wholesale Trade	0	10	90	270	360
9	COM3	Personal and Repair Services	0	10	90	270	360
10	COM4	Professional/Technical/ Business Services	0	20	90	360	480
11	COM5	Banks/Financial Institutions	0	20	90	180	360
12	COM6	Hospital	0	20	135	540	720
13	COM7	Medical Office/Clinic	0	20	135	270	540
14	COM8	Entertainment & Recreation	0	20	90	180	360
15	COM9	Theaters	0	20	90	180	360
16	COM10	Parking	0	5	60	180	360
		Industrial					
17	IND1	Heavy	0	10	90	240	360
18	IND2	Light	0	10	90	240	360
19	IND3	Food/Drugs/Chemicals	0	10	90	240	360
20	IND4	Metals/Minerals Processing	0	10	90	240	360
21	IND5	High Technology	0	20	135	360	540
22	IND6	Construction	0	10	60	160	320
		Agriculture					
23	AGR1	Agriculture	0	2	20	60	120
		Religion/Non-Profit					
24	REL1	Church/Membership Organization	0	5	120	480	960
		Government					
25	GOV1	General Services	0	10	90	360	480
26	GOV2	Emergency Response	0	10	60	270	360
		Education					
27	EDU1	Schools/Libraries	0	10	90	360	480
28	EDU2	Colleges/Universities	0	10	120	480	960

Repair times differ for similar damage states depending on building occupancy: thus simpler and smaller buildings will take less time to repair than more complex, heavily serviced or larger buildings. It has also been noted that large well-financed corporations can sometimes accelerate the repair time compared to normal construction procedures.

However, establishment of a more realistic repair time does not translate directly into business or service interruption. For some businesses, building repair time is largely irrelevant, because these businesses can rent alternative space or use spare industrial/commercial capacity elsewhere. These factors are reflected in Table 15.12, which provides multipliers to be applied to the values in Table 15.11 to arrive at estimates of business interruption for economic purposes. The factors in Tables 15.10, 15.11, and 15.12 are judgmentally derived, using ATC-13, Table 9.11 as a starting point.

The times resulting from the application of the Table 15.12 multipliers to the times shown in Table 15.11 represent median values for the probability of business or service interruption. For none and slight damage the time loss is assumed to be short, with cleanup by staff, but work can resume while slight repairs are done. For most commercial and industrial businesses that suffer moderate or extensive damage, the business interruption time is shown as short on the assumption that these concerns will find alternate ways of continuing their activities. The values in Table15.12 also reflect the fact that a proportion of business will suffer longer outages or even fail completely. Church and Membership Organizations generally quickly find temporary accommodation, and government offices also resume operating almost at once. It is assumed that hospitals and medical offices can continue operating, perhaps with some temporary rearrangement and departmental relocation if necessary, after moderate damage, but with extensive damage their loss of function time is also assumed to be equal to the total time for repair.

For other businesses and facilities, the interruption time is assumed to be equal to, or approaching, the total time for repair. This applies to residential, entertainment, theaters, parking, and religious facilities whose revenue or continued service, is dependent on the existence and continued operation of the facility.

The modifiers from Table 15.12 are multiplied by extended building construction times as follows:

$$LOF_{ds} = BCT_{ds} * MOD_{ds} \tag{15-14}$$

where:

LOF_{ds}	loss of function for damage state ds
BCT_{ds}	building construction and clean up time for damage state ds (See Table 15.11)
MOD_{ds}	construction time modifiers for damage state ds (See Table 15.12)

The median value applies to a large inventory of facilities. Thus, at moderate damage, some marginal businesses may close, while others will open after a day's cleanup. Even with extensive damage, some businesses will accelerate repair, while a number will also close or be demolished. For example, one might reasonably assume that a URM building that suffers moderate damage is more likely to be demolished than a newer building that suffers moderate, or even, extensive damage. If the URM building is an historic structure its likelihood of survival and repair will probably increase. There will also be a small number of extreme cases: the slightly damaged building that becomes derelict, or the extensively damaged building that continues to function for years, with temporary shoring, until an expensive repair is financed and executed.

Table 15.12: Building and Service Interruption Time Multipliers

No.	Label	Occupancy Class	Construction Time				
			Structural Damage State				
			None	Slight	Moderate	Extensive	Complete
		Residential					
1	RES1	Single Family Dwelling	0	0	0.5	1	1
2	RES2	Mobile Home	0	0	0.5	1	1
3	RES3	Multi Family Dwelling	0	0	0.5	1	1
4	RES4	Temporary Lodging	0	0	0.5	1	1
5	RES5	Institutional Dormitory	0	0	0.5	1	1
6	RES6	Nursing Home	0	0	0.5	1	1
		Commercial					
7	COM1	Retail Trade	0.5	0.1	0.1	0.3	0.4
8	COM2	Wholesale Trade	0.5	0.1	0.2	0.3	0.4
9	COM3	Personal and Repair Services	0.5	0.1	0.2	0.3	0.4
10	COM4	Professional/Technical/ Business Services	0.5	0.1	0.1	0.2	0.3
11	COM5	Banks/Financial Institutions	0.5	0.1	0.05	0.03	0.03
12	COM6	Hospital	0.5	0.1	0.5	0.5	0.5
13	COM7	Medical Office/Clinic	0.5	0.1	0.5	0.5	0.5
14	COM8	Entertainment & Recreation	0.5	0.1	1	1	1
15	COM9	Theaters	0.5	0.1	1	1	1
16	COM10	Parking	0.1	0.1	1	1	1
		Industrial					
17	IND1	Heavy	0.5	0.5	1	1	1
18	IND2	Light	0.5	0.1	0.2	0.3	0.4
19	IND3	Food/Drugs/Chemicals	0.5	0.2	0.2	0.3	0.4
20	IND4	Metals/Minerals Processing	0.5	0.2	0.2	0.3	0.4
21	IND5	High Technology	0.5	0.2	0.2	0.3	0.4
22	IND6	Construction	0.5	0.1	0.2	0.3	0.4
		Agriculture					
23	AGR1	Agriculture	0	0	0.05	0.1	0.2
		Religion/Non-Profit					
24	REL1	Church/Membership Organization	1	0.2	0.05	0.03	0.03
		Government					
25	GOV1	General Services	0.5	0.1	0.02	0.03	0.03
26	GOV2	Emergency Response	0.5	0.1	0.02	0.03	0.03
		Education					
27	EDU1	Schools/Libraries	0.5	0.1	0.02	0.05	0.05
28	EDU2	Colleges/Universities	0.5	0.1	0.02	0.03	0.03

Further discussion of the problem of estimating business interruption times is contained in Appendix B to this chapter.

An analogous situation exists for transportation and utility lifelines. For example, in many instances loss of portions of a freeway network can be offset by use of alternative surface streets. Occasionally, a bridge may represent the only means of access to a community. In this case, the downtime is directly significant and the economic losses may greatly exceed the cost of bridge replacement. The relationships between lifeline loss of function and loss of customer service is not direct because of the possibility of redundancy, alternative routings, and the fact that lifeline interruption is a routine occurrence for utility companies and common procedures are available to deal with it.

15.2.5 Relocation Expenses

Relocation costs may be incurred when the level of building damage is such that the building or portions of the building are unusable while repairs are being made. While relocation costs may include a number of expenses, in this model, only the following components are considered: **disruption costs** that include the cost of shifting and transferring, and the **rental** of temporary space. It should be noted that the burden of relocation expenses are not expected to be borne by the renter. Instead it is assumed that the building owners will incur the expense of moving their tenants to a new location. It should also be noted that a renter who has been displaced from a property due to earthquake damage would cease to pay rent to the owner of the damaged property and only pay rent to the new landlord. Therefore, the renter has no new rental expenses. It is assumed that the owner of the damaged property will pay the disruption costs for his renter. If the damaged property is owner occupied, then the owner will have to pay for disruption costs in addition to the cost of rent while he is repairing his building.

It is assumed in this model that it is unlikely that an occupant will relocate if a building is in the damage states none or slight. The exceptions are some government or emergency response services that need to be operational immediately after an earthquake. However these are considered to contribute very little to the total relocation expenses for a region and are ignored. Finally, it is assumed that entertainment, theaters, parking facilities and heavy industry (occupancy classes 14 to 17) will not relocate to new facilities. Instead they will resume operation when their facilities have been repaired or replaced. Relocation expenses are then a function of the floor area, the rental costs per day per square foot, a disruption cost, the expected days of loss of function for each damage state, the type of occupancy and the damage state itself. These are given by the following expression.

$$\mathrm{REL_i = FA_i} * \begin{bmatrix} (1-\%\mathrm{OO_i}) * \sum\limits_{\mathrm{ds=3}}^{5} (\mathrm{POSTR_{ds,i}} * \mathrm{DC_i}) + \\ \%\mathrm{OO_i} * \sum\limits_{\mathrm{ds=3}}^{5} (\mathrm{POSTR_{ds,i}} * (\mathrm{DC_i} + \mathrm{RENT_i} * \mathrm{RT_{ds}}) * \end{bmatrix} \tag{15-15}$$

where:

$\mathrm{REL_i}$ relocation costs for occupancy class i (i = 1-13 and 18-28)

FA_i	floor area of occupancy class i (in square feet)
$POSTR_{ds,i}$	probability of occupancy class i being in structural damage state ds, see Chapter 5
DC_i	disruption costs for occupancy i ($\$/ft^2$, See Table 15.13)
RT_{ds}	recovery time for damage state ds (See Table 15.11)
%OO	percent owner occupied for occupancy i (See Table 15.14)
$RENT_i$	rental cost ($\$/ft^2$/day) for occupancy i (See Table 15.13)

The default values for rental costs and disruption costs are typical 1994 values. However, actual values will vary from region to region; local numbers should be substituted for the default values for Default and User-Supplied Data Analyses. Regional numbers are commonly available from Chambers of Commerce or state and/or local regional economic development agencies.

Table 15.13: Rental Costs and Disruption Costs

No.	Label	Occupancy Class	Rental Cost ($/ft²/month)	Rental Cost ($/ft²/day)	Disruption Costs ($/ft²)
		Residential			
1	RES1	Single Family Dwelling	0.50	0.02	0.60
2	RES2	Mobile Home	0.35	0.01	0.60
3	RES3	Multi Family Dwelling	0.45	0.02	0.60
4	RES4	Temporary Lodging	1.50	0.05	0.60
5	RES5	Institutional Dormitory	0.30	0.01	0.60
6	RES6	Nursing Home	0.55	0.02	0.60
		Commercial			
7	COM1	Retail Trade	0.85	0.03	0.80
8	COM2	Wholesale Trade	0.35	0.01	0.70
9	COM3	Personal and Repair Services	1.00	0.03	0.70
10	COM4	Professional/Technical/ Business Services	1.00	0.03	0.70
11	COM5	Banks	1.25	0.04	0.70
12	COM6	Hospital	1.00	0.03	1.00
13	COM7	Medical Office/Clinic	1.00	0.03	1.00
14	COM8	Entertainment & Recreation	1.25	0.04	N/A
15	COM9	Theaters	1.25	0.04	N/A
16	COM10	Parking	0.25	0.01	N/A
		Industrial			
17	IND1	Heavy	0.15	0.01	N/A
18	IND2	Light	0.20	0.01	0.70
19	IND3	Food/Drugs/Chemicals	0.20	0.01	0.70
20	IND4	Metals/Minerals Processing	0.15	0.01	0.70
21	IND5	High Technology	0.25	0.01	0.70
22	IND6	Construction	0.10	0.00	0.70
		Agriculture			
23	AGR1	Agriculture	0.50	0.02	0.50
		Religion/Non/Profit			
24	REL1	Church/Membership Organization	0.75	0.03	0.70
		Government			
25	GOV1	General Services	1.00	0.03	0.70
26	GOV2	Emergency Response	1.00	0.03	0.70
		Education			
27	EDU1	Schools/Libraries	0.75	0.03	0.70
28	EDU2	Colleges/Universities	1.00	0.03	0.70

Table 15.14: Percent Owner Occupied

No.	Label	Occupancy Class	Percent Owner Occupied
		Residential	
1	RES1	Single Family Dwelling	75
2	RES2	Mobile Home	85
3	RES3	Multi Family Dwelling	35
4	RES4	Temporary Lodging	0
5	RES5	Institutional Dormitory	0
6	RES6	Nursing Home	0
		Commercial	
7	COM1	Retail Trade	55
8	COM2	Wholesale Trade	55
9	COM3	Personal and Repair Services	55
10	COM4	Professional/Technical/ Business Services	55
11	COM5	Banks	75
12	COM6	Hospital	95
13	COM7	Medical Office/Clinic	65
14	COM8	Entertainment & Recreation	55
15	COM9	Theaters	45
16	COM10	Parking	25
		Industrial	
17	IND1	Heavy	75
18	IND2	Light	75
19	IND3	Food/Drugs/Chemicals	75
20	IND4	Metals/Minerals Processing	75
21	IND5	High Technology	55
22	IND6	Construction	85
		Agriculture	
23	AGR1	Agriculture	95
		Religion/Non/Profit	
24	REL1	Church/Membership Organization	90
		Government	
25	GOV1	General Services	70
26	GOV2	Emergency Response	95
		Education	
27	EDU1	Schools/Libraries	95
28	EDU2	Colleges/Universities	90

15.2.6 Loss of Income

Business activity generates several types of income. First is income associated with capital, or property ownership. Business generates profits, and a portion of this is paid out to individuals (as well as to pension funds and other businesses) as dividends, while another portion, retained earnings, is plowed back into the enterprise. Businesses also make interest payments to banks and bondholders for loans. They pay rental income on property and make royalty payments for the use of tangible assets. Those in business for themselves, or in partnerships, generate a category called proprietary income, one portion of which reflects their profits and the other that reflects an imputed salary (e.g., the case of lawyers or dentists). Finally, the biggest category of income generated/paid is associated with labor. In most urban regions of the U.S., wage and salary income comprises more than 75% of total personal income payments.

It is possible to link income payments to various physical damage measures including sales, property values, and square footage. The latter approach is used here. Income losses occur when building damage disrupts economic activity. Income losses are the product of floor area, income realized per square foot and the expected days of loss of function for each damage state. Proprietor’s income losses are expressed as follows:

$$YLOS_i = (1\text{-}RF_i)*FA_i*INC_i*\sum_{ds=1}^{5} POSTR_{ds,i} * LOF_{ds} \qquad (15\text{-}16)$$

where:

$YLOS_i$	income losses for occupancy class i
FA_i	floor area of occupancy class i (in square feet)
INCi	income per day (per square foot) for occupancy class i (Table 15.15)
$POSTR_{ds,i}$	probability of occupancy i being in structural damage state ds, see Chapter 5
LOF_{ds}	loss of function time for damage state ds (see Equation 15-14)
RF_i	recapture factor for occupancy class i (see Section 15.2.6.1)

National estimates of sectoral income were obtained from the IMPLAN System, which in turn is based on U.S. Department of Commerce Bureau of Analysis data. The income data used was a three-year average to dampen cyclical variations especially prevalent for profit-related income. Income per square foot of floor space can then be derived by dividing income by the floor space occupied by a specific sector. As with losses and costs discussed above, income will vary considerably depending on regional economic conditions. Therefore, default values need to be adjusted for local conditions. Default values for floor space were derived from information in Table 4.7 of ATC-13.

15.2.6.1 Recapture Factors

The business-related losses from earthquakes can be recouped to some extent by working overtime after the event. For example, a factory that is closed for six weeks due to directly-caused structural damage or indirectly-caused shortage of supplies may work extra shifts in the weeks or months following its reopening. It is necessary that there be a demand for its output (including inventory buildup), but this is likely to be the case as undamaged firms try to overcome input shortages, other firms that were temporarily closed try to make-up their lost production as well, and firms outside the region press for resumption of export sales to them.

Obviously, this ability to "recapture" production will differ across industries. It will be high for those that produce durable output and lower for those that produce perishables or "spot" products (examples of the latter being utility sales to residential customers, hotel services, entertainment). Even some durable manufacturing enterprises would seem to have severe recapture limits because they already work three shifts per day; however, work on weekends, excess capacity, and temporary production facilities all can be used to make up lost sales.

The following table presents a set of recapture factors for the economic sectors used in the direct loss module. They are deemed appropriate for business disruptions lasting up to three months. As lost production becomes larger, it is increasingly difficult to recapture it for both demand-side and supply-side reasons. Recapture factors should be adjusted downward for such longer disruptions. A linear "decay" function is suggested, but only for that portion of production lost after the first three months. An end point of one year (i.e., no portion of lost sales beyond one year can be recaptured) would be appropriate.

Table of Recapture Factors

Occupancy	Wage Recapture (%)	Employment Recapture (%)	Income Recapture (%)	Output Recapture (%)
RES1	0	0	0	0
RES2	0	0	0	0
RES3	0	0	0	0
RES4	0.60	0.60	0.60	0.60
RES5	0.60	0.60	0.60	0.60
RES6	0.60	0.60	0.60	0.60
COM1	0.87	0.87	0.87	0.87
COM2	0.87	0.87	0.87	0.87
COM3	0.51	0.51	0.51	0.51
COM4	0.90	0.90	0.90	0.90
COM5	0.90	0.90	0.90	0.90
COM6	0.60	0.60	0.60	0.60
COM7	0.60	0.60	0.60	0.60
COM8	0.60	0.60	0.60	0.60
COM9	0.60	0.60	0.60	0.60
COM10	0.60	0.60	0.60	0.60
IND1	0.98	0.98	0.98	0.98
IND2	0.98	0.98	0.98	0.98
IND3	0.98	0.98	0.98	0.98
IND4	0.98	0.98	0.98	0.98
IND5	0.98	0.98	0.98	0.98
IND6	0.95	0.95	0.95	0.95
AGR1	0.75	0.75	0.75	0.75
REL1	0.60	0.60	0.60	0.60
GOV1	0.80	0.80	0.80	0.80
GOV2	0	0	0	0
EDU1	0.60	0.60	0.60	0.60
EDU2	0.60	0.60	0.60	0.60

15.2.7 Rental Income Losses

Rental income losses are the product of floor area, rental rates per sq. ft. and the expected days of loss of function for each damage state. Rental income losses include residential, commercial and industrial properties. It is assumed that a renter will pay full rent if the property is in the damage state none or slight. Thus rental income losses are calculated only for damage states 3, 4 and 5. It should be noted that rental income is based upon the percentage of floor area in occupancy i that is being rented (1 - $\%OO_i$).

$$RY_i = (1-\%OO_i) * FA_i * RENT_i * \sum_{ds=3}^{5} POSTR_{ds,i} * RT_{ds} \qquad (15\text{-}17)$$

where:

RY_i	rental income losses for occupancy i
$\%OO_i$	percent owner occupied for occupancy i (See Table 15.14)
FA_i	floor area of occupancy group i (in square feet)
$RENT_i$	rental cost ($\$/ft^2/day$) for occupancy i (See Table 15.13)
$POSTR_{ds,I}$	probability of occupancy i being in structural damage state ds, see Chapter 5
RT_{ds}	recovery time for damage state ds (See Table 15.11)

Rental rates vary widely with region and depend on local economic conditions including vacancy rate, the desirability of the neighborhood, and the desirability of the buildings. Regional and city rental rates are published annually by various real estate information services. The percentage rates given for owner occupancy are judgmentally based. For a given study region, census data will provide a more accurate measure for residential numbers.

15.2.8 Annualized Economic Loss to the General Building Stock

Using the approach described in this chapter, a methodology was developed to compute the expected annualized loss to the general building stock. Annualized economic loss is defined as the expected value of loss in any one year, and is developed by aggregating the losses and their exceedance probabilities. The annualized loss is equivalent to the area under a probabilistic loss curve such as the one shown in Figure 15.1. This integration combines the loss for each return period with its probability of exceedance.

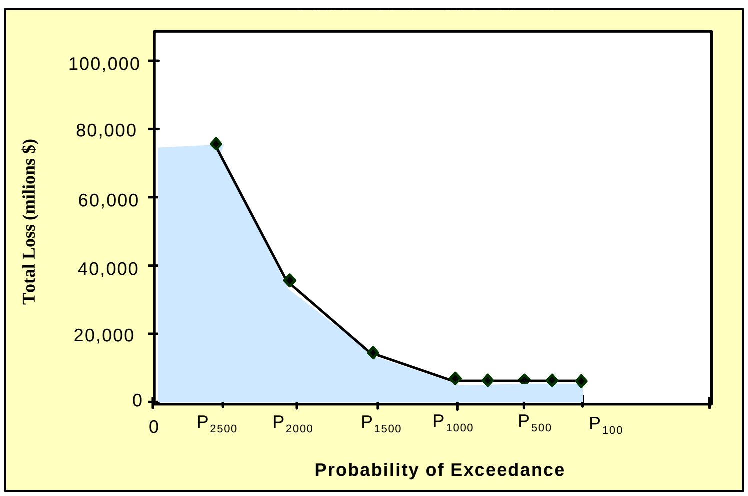


Figure 15-1: Probabilistic Loss Curve

The Methodology generates eight loss-probability pairs for the general building stock using the eight USGS probabilistic ground shaking return periods included with **HAZUS™**. A best-fit curve approach is used to generate a loss curve from the eight loss-probability pairs. Two different curve-fitting approaches are used; log-linear and exponential. The exponential relationship was found to generally provide a better fit for states with higher seismicity, while the log-linear approach was found to work better for states with lower seismicity. In **HAZUS^{TM}**, both relationships are used for each set of eight loss-probability pairs and the curve with the better fit is used as the basis for the annualized loss computation. Once the loss curve has been developed, the expected annual loss is computed by calculating the area under the curve.

15.2.9 Guidance for Estimate Using Advanced Data and Models Analysis

The methodological framework shown for the Default and User-Supplied Data Analyses will still apply for this type of analysis. However, depending on the type of analysis required, much more detailed inventory and cost information can be obtained from consultants. In the area of cost, professional building cost consultants maintain detailed records of costs and trends, and have knowledge of local building practices that might affect a loss estimate. Inventory improvement might include substantial "windshield" surveys that can greatly augment the accuracy of building type and occupancy information. It should be noted that while the windshield survey has limitations in procuring detailed information on structural types it is effective in procuring the kind of size and occupancy information necessary for the generic cost estimating proposed in this methodology.

Certain kinds of Advanced Data and Models Analysis estimates, for example one focused on the implications of hospital or specific industry losses, would require individual building cost estimates (together with similar individual building damage estimates) that might result in costs considerably different than the typical aggregated costs provided as part of the default database provided with this methodology.

Table 15.15: Proprietor's Income

No	Label	Occupancy Class	Income		Wages per Square Foot per Day	Employees per Square Foot	Output per Square Foot per Day
			per Square Foot per Year	per Square Foot per Day			
		Residential					
1	RES1	Single Family Dwelling	0.000	0.000	0.000	0.000	0.000
2	RES2	Mobile Home	0.000	0.000	0.000	0.000	0.000
3	RES3	Multi Family Dwelling	0.000	0.000	0.000	0.000	0.000
4	RES4	Temporary Lodging	26.415	0.072	0.170	0.003	0.379
5	RES5	Institutional Dormitory	0.000	0.000	0.000	0.000	0.000
6	RES6	Nursing Home	44.025	0.121	0.284	0.005	0.632
		Commercial					
7	COM1	Retail Trade	16.299	0.045	0.156	0.004	0.330
8	COM2	Wholesale Trade	26.731	0.073	0.192	0.002	0.429
9	COM3	Personal and Repair Services	35.220	0.096	0.227	0.004	0.506
10	COM4	Professional/Technical/ Business Services	277.520	0.760	0.270	0.004	0.739
11	COM5	Banks	316.683	0.868	0.440	0.006	2.399
12	COM6	Hospital	44.025	0.121	0.284	0.005	0.632
13	COM7	Medical Office/Clinic	88.050	0.241	0.568	0.010	1.264
14	COM8	Entertainment & Recreation	161.474	0.442	0.352	0.007	0.797
15	COM9	Theaters	52.830	0.145	0.341	0.006	0.759
16	COM10	Parking	0.000	0.000	0.000	0.000	0.000
		Industrial					
17	IND1	Heavy	66.808	0.183	0.303	0.003	1.281
18	IND2	Light	66.808	0.183	0.303	0.003	1.281
19	IND3	Food/Drugs/Chemicals	89.077	0.244	0.405	0.004	1.708
20	IND4	Metals/Minerals Processing	202.395	0.555	0.313	0.003	1.355
21	IND5	High Technology	133.616	0.366	0.607	0.006	2.561
22	IND6	Construction	65.133	0.178	0.328	0.005	1.269
		Agriculture					
23	AGR1	Agriculture	61.810	0.169	0.067	0.004	0.632
		Religion/Non/Profit					
24	REL1	Church/Membership Organization	35.220	0.096	0.227	0.004	1.264
		Government					
25	GOV1	General Services	28.925	0.079	2.180	0.025	0.506
26	GOV2	Emergency Response	0.000	0.000	3.314	0.038	0.581
		Education					
27	EDU1	Schools/Libraries	44.025	0.121	0.284	0.005	2.449
28	EDU2	Colleges/Universities	88.050	0.241	0.568	0.010	3.722

15.3 Description of Methodology: Lifelines

This section describes the methodologies used to estimate lifeline related direct economic losses. Direct physical damage to transportation and utility lifelines was discussed in Chapters 7 and 8, respectively. Estimation of direct economic losses for the extended network lifelines such as highways, railroads, water supply, and power supply, depends on the inventory data providing the location of all nodes and links, and the models relating ground motions to damage.

Direct economic losses are computed based on (1) probabilities of being in a certain damage state ($P[D_S \geq ds_i]$), (2) the replacement value of the component, and (3) damage ratios (DR_i) for each damage state, ds_i. Economic losses are evaluated by multiplying the compounded damage ratio (DR_C) by the replacement value. The compounded damage ratio is computed as the probabilistic combination of damage ratios as follows.

$$DR_c = \sum_{i=2}^{5} DR_i \times P[ds_i] \tag{15-18}$$

where $P[ds_i]$ is the probability of being in damage state i, and 1, 2, 3, 4 and 5 are associated with damage states none, slight, moderate, extensive and complete. No losses are associated with damage state 1, therefore, the summation is from i = 2 to 5.

The probability of being in or exceeding a certain damage state ($P[D_S > ds_i$ | PGA, PGV or PGD]), for each component, were presented in Chapter 7 and Chapter 8. The probabilities of being in a particular damage state are as follows:

$$P[D_s = ds_1|\text{PGA or PGD}] = 1 - P[D_s \geq ds_2 \mid \text{PGA or PGD}] = \mathbf{P_1} \tag{15-19}$$

$$P[D_s = ds_2|\text{PGA or PGD}] = P[D_s \geq ds_2 \mid \text{PGA or PGD}] - P[D_s \geq ds_3 \mid \text{PGA or PGD}] = \mathbf{P_2} \tag{15-20}$$

$$P[D_s = ds_3|\text{PGA or PGD}] = P[D_s \geq ds_3 \mid \text{PGA or PGD}] - P[D_s \geq ds_4 \mid \text{PGA or PGD}] = \mathbf{P_3} \tag{15-21}$$

$$P[D_s = ds_4|\text{PGA or PGD}] = P[D_s \geq ds_4 \mid \text{PGA or PGD}] - P[D_s \geq ds_5 \mid \text{PGA or PGD}] = \mathbf{P_4} \tag{15-22}$$

$$P[D_s = ds_5|\text{PGA or PGD}] = P[D_s \geq ds_5 \mid \text{PGA or PGD}] = \mathbf{P_5} \tag{15-23}$$

The estimates of replacement values of all lifeline system components are given in Tables 15.16 and 15.17. Table 15.16 provides the replacement values for the components of the transportation system, while Table 15.17 provides the replacement values for the utility system components. Most of the replacement value data comes from ATC-13 and ATC-25. These values are rough estimates and should only be used as a guide. It is expected that that user will input replacement values based on specific knowledge of the lifeline components in the study area. In cases where a range is given in Tables 15.16 and 15.17, the default value is set equal to the midpoint of the range.

Table 15.16: Default Replacement Values of Transportation System Components

System	Replacement Value (thous. $)	Label	Component Classification
Highway	10,000	HRD1	Major Roads (value based on one km length, 4 lanes)
	5,000	HRD2	Urban Streets (value based on one km length, 2 lanes)
	20,000	HWB1/HWB2	Major Bridges
	5,000	HWB8, 9, 10, 11, 15, 16, 20, 21, 22, 23, 26, 27	Continuous Bridges
	1,000	HWB3, 4, 5, 6, 7, 12, 13, 14, 17, 18, 19, 24, 25, 28	Other Bridges
	20,000	HTU1	Highway Bored/Drilled Tunnel (value based on liner)
	20,000	HTU2	Highway Cut and Cover Tunnel (value based on liner)
Rail	1,500	RTR1	Rail Track (value based on one km length)
	5,000	RBR1	Rail Bridge - Seismically Designed
	5,000	RBR2	Rail Bridge - Conventionally Designed
	10,000	RTU1	Rail Bored/Drilled Tunnel (value based on liner)
	10,000	RTU2	Rail Cut and Cover Tunnel (value based on liner)
	2,000	RST1	Rail Urban Station (C2L)
	2,000	RST2	Rail Urban Station (S2L)
	2,000	RST3	Rail Urban Station (S1L)
	2,000	RST4	Rail Urban Station (S5L)
	2,000	RST5	Rail Urban Station (PC1)
	2,000	RST6	Rail Urban Station (C3L)
	2,000	RST7	Rail Urban Station (W1L)
	3,000	RFF1	Rail Fuel Facility w/ Anchored Tanks, w/ BU Power
	3,000	RFF2	Rail Fuel Facility w/ Anchored Tanks, wo/ BU Power
	3,000	RFF3	Rail Fuel Facility w/ Unanchored Tanks, w/ BU Power
	3,000	RFF4	Rail Fuel Facility w/ Unanchored Tanks, wo/ BU Power
	3,000	RFF5	Rail Fuel Facility w/ Buried Tanks
	3,000	RDF1	Rail Dispatch Facility w/ Anchored Sub-Comp., w/ BU Power
	3,000	RDF2	Rail Dispatch Facility w/ Anchored Sub-Comp., wo/ BU Power
	3,000	RDF3	Rail Dispatch Facility w/ Unanchored Sub-Comp., w/ BU Power
	3,000	RDF4	Rail Dispatch Facility w/ Unanchored. Sub-Comp., w/0 BU Power
	2,800	RMF1	Rail Maintenance Facility (C2L)
	2,800	RMF2	Rail Maintenance Facility (S2L)
	2,800	RMF3	Rail Maintenance Facility (S1L)
	2,800	RMF4	Rail Maintenance Facility (S5L)
	2,800	RMF5	Rail Maintenance Facility (PC1)
	2,800	RMF6	Rail Maintenance Facility (C3L)
	2,800	RMF7	Rail Maintenance Facility (W1)

Table 15.16: Default Replacement Values of Transportation System Components (con't)

System	Replacement Value (thous $)	Label	Component Classification
Light Rail	1,500	LTR1	Light Rail Track
	5,000	LBR1	Light Rail Bridge - Seismically Designed/Retrofitted
	5,000	LBR2	Light Rail Bridge - Conventionally Designed
	10,000	LTU1	Light Rail Bored/Drilled Tunnel (value based on liner)
	10,000	LTU2	Light Rail Cut and Cover Tunnel (value based on liner)
	2,000	LDC1	Light Rail DC Substation w/ Anchored Sub-Components
	2,000	LDC2	Light Rail DC Substation w/ Unanchored Sub-Comp.
	3,000	LDF1	Lt Rail Dispatch Fac w/ Anchored Sub-Comp., w/ BU Power
	3,000	LDF2	Lt Rail Dispatch Fac w/ Anchored Sub-Comp., wo/ BU Power
	3,000	LDF3	Lt Rail Dispatch Fac w/ Unanchored Sub-Comp., w/ BU Power
	3,000	LDF4	Lt Rail Dispatch Fac w/ Unanchored Sub-Comp., wo/ BU Power
	2,600	LMF1	Light Rail Maintenance Facility (C2L)
	2,600	LMF2	Light Rail Maintenance Facility (S2L)
	2,600	LMF3	Light Rail Maintenance Facility (S1L)
	2,600	LMF4	Light Rail Maintenance Facility (S5L)
	2,600	LMF5	Light Rail Maintenance Facility (PC1)
	2,600	LMF6	Light Rail Maintenance Facility (C3L)
	2,600	LMF7	Light Rail Maintenance Facility (W1)
Bus	1,000	BPT1	Bus Urban Station (C2L)
	1,000	BPT2	Bus Urban Station (S2L)
	1,000	BPT3	Bus Urban Station (S1L)
	1,000	BPT4	Bus Urban Station (S5L)
	1,000	BPT5	Bus Urban Station (PC1)
	1,000	BPT6	Bus Urban Station (C3L)
	1,000	BPT7	Bus Urban Station (W1)
	150	BFF1	Bus Fuel Facility w/ Anchored Tanks, w/ BU Power
	150	BFF2	Bus Fuel Facility w/ Anchored Tanks, wo/ BU Power
	150	BFF3	Bus Fuel Facility w/ Unanchored Tanks, w/ BU Power
	150	BFF4	Bus Fuel Facility w/ Unanchored Tanks, wo/ BU Power
	150	BFF5	Bus Fuel Facility w/ Buried Tanks
	400	BDF1	Bus Dispatch Fac. w/ Anchored. Sub-Comp., w/ BU Power
	400	BDF2	Bus Dispatch Fac. w/ Anchored. Sub-Comp., wo/ BU Power
	400	BDF3	Bus Dispatch Fac. w/ Unanchored. Sub-Comp., w/ BU Power
	400	BDF4	Bus Dispatch Fac. w/ Unanchored. Sub-Comp., wo/ BU Power
	1,300	BMF1	Bus Maintenance Facility (C2L)
	1,300	BMF2	Bus Maintenance Facility (S2L)
	1,300	BMF3	Bus Maintenance Facility (S1L)
	1,300	BMF4	Bus Maintenance Facility (S5L)
	1,300	BMF5	Bus Maintenance Facility (PC1)
	1,300	BMF6	Bus Maintenance Facility (C3L)
	1,300	BMF7	Bus Maintenance Facility (W1)

Table 15.16: Default Replacement Values of Transportation System Components (con't)

System	Replacement Value (thous $)	Label	Component Classification
Port	1,500	PWS1	Port Waterfront Structures
	2,000	PEQ1	Anchored Port Handling Equipment
	2,000	PEQ2	Unanchored Port Handling Equipment
	1,200	PWH1	Port Warehouses (C2L)
	1,200	PWH2	Port Warehouses (S2L)
	1,200	PWH3	Port Warehouses (S1L)
	1,200	PWH4	Port Warehouses (S5L)
	1,200	PWH5	Port Warehouses (PC1)
	1,200	PWH6	Port Warehouses (C3L)
	1,200	PWH7	Port Warehouses (W1)
	2,000	PFF1	Port Fuel Facility w/ Anchored Tanks, w/ BU Power
	2,000	PFF2	Port Fuel Facility w/ Anchored Tanks, wo/ BU Power
	2,000	PFF3	Port Fuel Facility w/ Unanchored Tanks, w/ BU Power
	2,000	PFF4	Port Fuel Facility w/ Unanchored Tanks, wo/ BU Power
	2,000	PFF5	Port Fuel Facility w/ Buried Tanks
Ferry	1,500	FWS1	Ferry Waterfront Structures (Value for 7,500 ft^2 facility)
	1,000	FPT1	Ferry Passenger Terminals (C2L)
	1,000	FPT2	Ferry Passenger Terminals (S2L)
	1,000	FPT3	Ferry Passenger Terminals (S1L)
	1,000	FPT4	Ferry Passenger Terminals (S5L)
	1,000	FPT5	Ferry Passenger Terminals (PC1)
	1,000	FPT6	Ferry Passenger Terminals (C3L)
	1,000	FPT7	Ferry Passenger Terminals (W1)
	400	FFF1	Ferry Fuel Facility w/ Anchored Tanks, w/ BU Power
	400	FFF2	Ferry Fuel Facility w/ Anchored Tanks, wo/ BU Power
	400	FFF3	Ferry Fuel Facility w/ Unanchored Tanks, w/ BU Power
	400	FFF4	Ferry Fuel Facility w/ Unanchored Tanks, wo/ BU Power
	400	FFF5	Ferry Fuel Facility w/ Buried Tanks
	200	FDF1	Ferry Dispatch Fac. w/ Anchored. Sub-Comp., w/ BU Power
	200	FDF2	Ferry Dispatch Fac. w/ Anchored. Sub-Comp., wo/ BU Power
	200	FDF3	Ferry Dispatch Fac. w/ Unanchored. Sub-Comp., w/ BU Power
	200	FDF4	Ferry Dispatch Fac. w/ Unanchored. Sub-Comp., wo/ BU Power
	520	FMF1	Ferry Maintenance Facility (C2L)
	520	FMF2	Ferry Maintenance Facility (S2L)
	520	FMF3	Ferry Maintenance Facility (S1L)
	520	FMF4	Ferry Maintenance Facility (S5L)
	520	FMF5	Ferry Maintenance Facility (PC1)
	520	FMF6	Ferry Maintenance Facility (C3L)
	520	FMF7	Ferry Maintenance Facility (W1)

Table 15.16: Default Replacement Values of Transportation System Components (con't)

System	Replacement Value (thous $)	Label	Component Classification
Airport	5,000	ACT1	Airport Control Towers (C2L)
	5,000	ACT2	Airport Control Towers (S2L)
	5,000	ACT3	Airport Control Towers (S1L)
	5,000	ACT4	Airport Control Towers (S5L)
	5,000	ACT5	Airport Control Towers (PC1)
	5,000	ACT6	Airport Control Towers (C3L)
	5,000	ACT7	Airport Control Towers (W1)
	28,000	ARW1	Airport Runways
	8,000	ATB1	Airport Terminal Buildings (C2L)
	8,000	ATB2	Airport Terminal Buildings (S2L)
	8,000	ATB3	Airport Terminal Buildings (S1L)
	8,000	ATB4	Airport Terminal Buildings (S5L)
	8,000	ATB5	Airport Terminal Buildings (PC1)
	8,000	ATB6	Airport Terminal Buildings (C3L)
	8,000	ATB7	Airport Terminal Buildings (W1)
	1,400	APS1	Airport Parking Structures (C2L)
	1,400	APS2	Airport Parking Structures (S2L)
	1,400	APS3	Airport Parking Structures (S1L)
	1,400	APS4	Airport Parking Structures (S5L)
	1,400	APS5	Airport Parking Structures (PC1)
	1,400	APS65	Airport Parking Structures (C3L)
	5,000	AFF1	Airport Fuel Facility w/ Anchored Tanks, w/ BU Power
	5,000	AFF2	Airport Fuel Facility w/ Anchored Tanks, wo/ BU Power
	5,000	AFF3	Airport Fuel Facility w/ Unanchored Tanks, w/ BU Power
	5,000	AFF4	Airport Fuel Facility w/ Unanchored Tanks, wo/ BU Power
	5,000	AFF5	Airport Fuel Facility w/ Buried Tanks
	3,200	AMF1	Airport Maintenance & Hanger Facility
	8,000	ATBU1	Airport - General
	2,000	AFH1	Heliport
	500	AFO1	Seaport / Stolport / Gliderport / Seaplane

Table 15.17: Default Replacement Values of Utility System Components

System	Replacement Value (thous $)	Label	Component Classification
Potable Water	1	PWP1	Brittle Pipe (per break)
	1	PWP2	Ductile Pipe (per break)
	30,000	PWT1	Small WTP with Anchored Components < 50 MGD
	30,000	PWT2	Small WTP with Unanchored Components <50 MGD
	100,000	PWT3	Medium WTP with Anchored Components 50-200 MGD
	100,000	PWT4	Medium WTP with Unanchored Components 50-200 MGD
	360,000	PWT5	Large WTP with Anchored Components >200 MGD
	360,000	PWT6	Large WTP with Unanchored Components >200 MGD
	400	PWE1	Wells
	1,500	PST1	On Ground Anchored Concrete Tank
	1,500	PST2	On Ground Unanchored Concrete Tank
	800	PST3	On Ground Anchored Steel Tank
	800	PST4	On Ground Unanchored Steel Tank
	800	PST5	Above Ground Anchored Steel Tank
	800	PST6	Above Ground Unanchored Steel Tank
	30	PST7	On Ground Wood Tank
	150	PPP1	Small Pumping Plant with Anchored Equipment <10 MGD
	150	PPP2	Small Pumping Plant with Unanchored Equipment <10 MGD
	525	PPP3	Medium/Large Pumping Plant with Anchored Equipment >10 MGD
	525	PPP4	Med./Large Pumping Plant with Unanchored Equipment >10 MGD
Waste Water	1	WWP1	Brittle Pipe (per break)
	1	WWP2	Ductile Pipe (per break)
	60,000	WWT1	Small WWTP with Anchored Components <50 MGD
	60,000	WWT2	Small WWTP with Unanchored Components <50 MGD
	200,000	WWT3	Medium WWTP with Anchored Components 50-200 MGD
	200,000	WWT4	Medium WWTP with Unanchored Components 50-200 MGD
	720,000	WWT5	Large WWTP with Anchored Components >200 MGD
	720,000	WWT6	Large WWTP with Unanchored Components >200 MGD
	300	WLS1	Small Lift Stations with Anchored Components <10 MGD
	300	WLS2	Small Lift Stations with Unanchored Components <10 MGD
	1,050	WLS3	Medium/Large Lift Stations with Anchored Components >10 MGD
	1,050	WLS4	Med./Large Lift Stations with Unanchored Components >10 MGD
Oil	1	OIP1	Welded Steel Pipe with Gas Welded Joints (per break)
	1	OIP2	Welded Steel Pipe with Arc Welded Joints (per break)
	175,000	ORF1	Small Refinery with Anchored Equipment <100,000 bl/day
	175,000	ORF2	Small Refinery with Unanchored Equipment <100,000 bl/day
	750,000	ORF3	Medium/Large Refinery with Anchored Equipment >100,000 bl/day
	750,000	ORF4	Medium/Large Refinery with Unanchored Equipment >100,000 bl/day
	1,000	OPP1	Pumping Plant with Anchored Equipment
	1,000	OPP2	Pumping Plant with Unanchored Equipment
	2,000	OTF1	Tank Farms with Anchored Tanks
	2,000	OTF2	Tank Farms with Unanchored Tanks

Table 15.17: Default Replacement Values of Utility System Components (con't)

System	Replacement Value (thous $)	Label	Component Classification
Natural Gas	1	NGP1	Welded Steel Pipe with Gas Welded Joints (per break)
	1	NGP2	Welded Steel Pipe with Arc Welded Joints (per break)
	1,000	NGC1	Compressor Stations with Anchored Components
	1,000	NGC2	Compressor Stations with Unanchored Components
Electric Power Systems	10,000	ESS1	Low voltage (115 KV) substation, anchored comp.
	10,000	ESS2	Low voltage (115 KV) substation, unanchored comp.
	20,000	ESS3	Medium Voltage (230 KV) substation, anchored comp.
	20,000	ESS4	Medium Voltage (230 KV) substation, unanchored. comp.
	50,000	ESS5	High Voltage (500 KV) substation, anchored comp.
	50,000	ESS6	High Voltage (500 KV) substation, unanchored comp.
	3	EDC1	Distribution Circuits with seismically designed components
	3	EDC2	Distribution Circuits with standard components
	100,000	EPP1	Small Power Plants with Anchored Comp < 100 MW
	100,000	EPP2	Small Power Plants with Unanchored Comp <100 MW
	500,000	EPP3	Medium/Large Power Plants with Anchored Comp >100 MW
	500,000	EPP4	Medium/Large Power Plants with Unanchored Comp >100 MW
Commu-nication Systems	5,000	CCO1	Central Office with Anchored Components, w/BU Power
	5,000	CCO2	Central Office with Anchored Components, w/o BU Power
	5,000	CCO3	Central Office with Unanchored Components, w/BU Power
	5,000	CCO4	Central Office with Unanchored Components, w/o BU Power
	2,000	CBR1	Radio Broadcasting Station
	2,000	CBT1	TV Broadcasting Station
	2,000	CBW1	Weather Broadcasting Station
	2,000	CBO1	Other Communication Facility

15.3.1 Transportation Systems

This section describes the methodologies used to estimate direct economic losses related to transportation system damage. Transportation systems include highway, railway, light rail, bus, port, ferry, and airport systems. Damage models for each of these systems was discussed in detail in Chapter 7.

15.3.1.1 Highway Systems

In this subsection, damage ratios are presented for the following highway system components: roadways; bridges; tunnels. Damage ratios for bridges are expressed as a fraction of the component (bridge) replacement cost. Damage ratios for roadways are expressed as a fraction of the roadway replacement cost per unit length. Damage ratios for highway tunnels are expressed as a fraction of the liner replacement cost per unit length. The damage ratios for roadways, tunnels, and bridges are presented in Table 15.18.

Table 15.18: Damage Ratios for Highway System Components

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Roadways	slight	0.05	0.01 to 0.15
	moderate	0.20	0.15 to 0.4
	extensive/ complete	0.70	0.4 to 1.0
Tunnel's Lining	slight	0.01	0.01 to 0.15
	moderate	0.30	0.15 to 0.4
	extensive	0.70	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Bridges	slight	0.03	0.01 to 0.03
	moderate	0.08	0.02 to 0.15
	extensive	0.25	0.10 to 0.40
	complete	1.00*	0.30 to 1.00

* If the number of spans is greater than two, then the best estimate damage ratio for complete damage is [2/(number of spans)]

15.3.1.2 Railway Systems

In this subsection, damage ratios are presented for the following railway system components: tracks/roadbeds; bridges; tunnels; facilities. Damage ratios associated with bridges and facilities are expressed as a fraction of the component replacement cost. Damage ratios for tracks are expressed as a fraction of the replacement cost per length. Damage ratios for railway tunnels are expressed as a fraction of the liner replacement cost per unit length.

The damage ratios for railway bridges, fuel facilities, dispatch facilities, and urban stations and maintenance facilities, are presented in Table 15.19. The damage ratios for railway tracks and tunnels are the same as for urban roads and tunnels for the highway systems presented in Section 15.3.1.1. The damage ratios for bridges are computed in the same manner as for highway bridges. For a given damage state, the damage ratios for fuel and dispatch facilities are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (fuel or dispatch facility) value. The subcomponents information is presented in Table 15D.1 of Appendix 15D.

Table 15.19: Damage Ratios for Railway System Components

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Bridges	slight moderate extensive complete	0.12 0.19 0.40 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Fuel Facilities	slight moderate extensive complete	0.15 0.39 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Dispatch Facilities	slight moderate extensive complete	0.04 0.4 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Urban Stations and Maintenance Facilities	slight moderate extensive complete	0.10 0.40 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.1.3 Light Rail Systems

In this subsection, damage ratios are presented for the following light rail system components: tracks/roadbeds; bridges; tunnels; facilities. Damage ratios for bridges and facilities are expressed as a fraction of the component replacement cost. Damage ratios for tracks are expressed as a fraction of the replacement value per unit length. Damage ratios for light rail tunnels are expressed as a fraction of the linear replacement cost.

The damage ratios for DC substations are presented in Table 15.20. The damage ratios for light rail tracks and tunnels are the same as for urban roads and tunnels for highway systems presented in Section 15.3.1.1. The damage ratios for dispatch facilities and bridges are the same as those for railway systems presented in Section 15.3.1.2. The damage ratios for the subcomponents of DC substations are estimated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total substation value. The subcomponent information for the DC substations are presented in Table 15D.2 of Appendix 15D.

Table 15.20: Damage Ratios for DC Substations

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
DC Substations	slight moderate extensive complete	0.04 0.4 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.1.4 Bus Systems

In this subsection, damage ratios are presented for the following bus system components: urban stations; maintenance, fuel, and dispatch facilities. Damage ratios for these components are expressed as a fraction of the component replacement cost.

The damage ratios for bus system components are presented in Table 15.21. The damage ratios for urban stations and maintenance facilities are the same as those for railway systems presented in Section 15.3.1.2. The damage ratios for fuel and dispatch facilities are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (fuel or dispatch facility) value. The subcomponent information is presented in Table 15D.3 of Appendix 15D.

Table 15.21: Damage Ratios for Bus System Components

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Fuel Facilities	slight moderate extensive complete	0.15 0.39 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Dispatch Facilities	slight moderate extensive complete	0.06 0.4 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.1.5 Port Systems

In this subsection, damage ratios are presented for the following port system components: waterfront structures (e.g., wharves, piers and sea-walls); cranes and cargo handling equipment; fuel facilities; warehouses. Damage ratios for these components are expressed as a fraction of the component replacement cost.

The damage ratios for port system components are presented in Table 15.22. The damage ratios for fuel facilities are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (fuel facility) value. The subcomponent information is presented in Table 15D.4 of Appendix 15D.

Table 15.22: Damage Ratios for Port System Components

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Waterfront Structures	slight	0.10	0.01 to 0.15
	moderate	0.40	0.15 to 0.4
	extensive	0.80	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Cranes/Cargo Handling Equipment	slight	0.05	0.01 to 0.15
	moderate	0.25	0.15 to 0.4
	extensive/ complete	0.75	0.4 to 1.0
Warehouses	slight	0.10	0.01 to 0.15
	moderate	0.40	0.15 to 0.4
	extensive	0.80	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Fuel Facilities	slight	0.16	0.01 to 0.15
	moderate	0.39	0.15 to 0.4
	extensive	0.8	0.4 to 0.8
	complete	1.00	0.8 to 1.0

15.3.1.6 Ferry Systems

In this subsection, damage ratios are presented for the following ferry system components: waterfront structures (e.g., wharf's piers and sea-walls); fuel, maintenance, and dispatch facilities; passenger terminals. Damage ratios for ferry system components are expressed as a fraction of the component replacement cost.

The damage ratios for ferry system components are presented in Table 15.23. The damage ratios for waterfront structures are the same as those for port systems. The damage ratios for maintenance and dispatch facilities are the same as those for railway systems. The damage ratios for passenger terminals are the same as those for urban stations in railway systems. The damage ratios for fuel facilities are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (fuel facility) value. The subcomponent information is presented in Table 15D.4 of Appendix 15D.

Table 15.23: Damage Ratios for Ferry System Component

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Fuel Facilities	slight moderate extensive complete	0.15 0.37 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.1.7 Airport Systems

In this subsection, damage ratios are presented for the following airport system components: runways; control towers; fuel facilities; terminal buildings; maintenance and hangar facilities; parking structures. Damage ratios for the airport system components are expressed as a fraction of the component replacement cost.

The damage ratios for airport system components are presented in Table 15.24. The damage ratios for fuel facilities are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (fuel facility) value. The subcomponent information is presented in Table 15D.4 of Appendix 15D.

Table 15.24: Damage Ratios for Airport System Components

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Runways	slight moderate extensive complete	0.05 0.05 0.8 1.0	0.01 to 0.4 0.01 to 0.4 0.4 to 0.8 0.8 to 1.0
Control Towers	slight moderate extensive complete	0.10 0.40 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Terminal Buildings	slight moderate extensive complete	0.10 0.40 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

Table 15.24: Damage Ratios for Airport System Components (Continued)

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Parking Structures	slight moderate extensive complete	0.10 0.40 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Fuel Facilities	slight moderate extensive complete	0.14 0.37 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Maintenance & Hangar Facilities	slight moderate extensive complete	0.10 0.40 0.80 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.2 Utility Systems

This section describes the methodologies used to estimate direct economic losses related to utility system damage. Utility systems include potable water, waste water, oil, natural gas, electric power, and communication systems. The estimation of the direct economic losses associated with each of these systems is presented in the following sections.

15.3.2.1 Potable Water Systems

In this subsection, damage ratios are presented for the following potable water system components: pipelines; water treatment plants; wells; storage tanks; pumping plants. Damage ratios for these components are expressed as a fraction of the component replacement cost.

The damage ratios for potable water system components are presented in Table 15.25. The damage ratios for water treatment plants, wells, and pumping plants are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component value. The subcomponent information is presented in Table 15D.5 of Appendix 15D.

Table 15.25: Damage Ratios for Potable Water Systems

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Pipelines	leak break	0.10* 0.75*	0.05 to 0.20 0.5 to 1.0
Water Treatment Plants	slight	0.08	0.01 to 0.15
	moderate	0.4	0.15 to 0.4
	extensive	0.77	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Tanks	slight	0.20	0.01 to 0.15
	moderate	0.40	0.15 to 0.4
	extensive	0.8	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Wells and Pumping Plants	slight	0.05	0.01 to 0.15
	moderate	0.38	0.15 to 0.4
	extensive	0.8	0.4 to 0.8
	complete	1.00	0.8 to 1.0

* % of the replacement cost for one 20 ft. pipe segment

15.3.2.2 Waste Water Systems

In this subsection, damage ratios are presented for the following waste water system components: underground sewers and interceptors; waste water treatment plants; lift stations. Damage ratios for these components are expressed as a fraction of the component replacement cost.

The damage ratios for waste water system components are presented in Table 15.26. The damage ratios for lift stations are same as those for pumping plants in potable water systems presented in Section 15.3.2.2. The damage ratios for waste water treatment plants are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component value. The subcomponent information is presented in Table 15D.6 of Appendix 15D.

Table 15.26: Damage Ratios for Waste Water Systems

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Underground Sewers & Interceptors	leak break	0.10 0.75	0.05 to 0.20 0.5 to 1.0
Waste Water Treatment Plants	slight moderate extensive complete	0.10 0.37 0.65 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.2.3 Oil Systems

In this subsection, damage ratios are presented for the following oil system components: buried pipes; refineries; pumping plants; tank farms. Damage ratios for these components are expressed as a function of the component replacement cost.

The damage ratios for oil system components are presented in Table 15.27. The damage ratios for refineries, pumping plants, and tank farms are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component value. The subcomponent information is presented in Table 15D.7 of Appendix 15D.

Table 15.27: Damage Ratios for Oil Systems

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Buried Pipes	leak break	0.10 0.75	0.05 to 0.20 0.5 to 1.0
Refineries	slight moderate extensive complete	0.09 0.23 0.78 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Pumping Plants	slight moderate extensive complete	0.08 0.4 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0
Tank Farms	slight moderate extensive complete	0.13 0.4 0.8 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.3.2.4 Natural Gas Systems

In this subsection, damage ratios are presented for the following gas system components: buried pipes; compressor stations. Damage ratios for these components are expressed as a fraction of the component replacement cost. The damage ratios for buried pipes are the same as those for oil systems. The damage ratios for compressor stations are the same as those for pumping plants in the oil system.

15.3.2.5 Electric Power Systems

In this subsection, damage ratios are presented for the following electric power system components: substations; distribution circuits; generation plants. Damage ratios for these components are expressed as a fraction of the component replacement cost.

The damage ratios for electric power system components are presented in Table 15.28. The damage ratios for substations and generation plants are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component value. The subcomponent information is presented in Table 15D.8 & 15D.9 of Appendix 15D.

Table 15.28: Damage Ratios for Electric Power Systems

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Substations	slight	0.05	0.01 to 0.15
	moderate	0.11	0.15 to 0.4
	extensive	0.55	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Distribution Circuits	slight	0.05	0.01 to 0.15
	moderate	0.15	0.15 to 0.4
	extensive	0.60	0.4 to 0.8
	complete	1.00	0.8 to 1.0
Generation Plants	slight	0.08	0.01 to 0.15
	moderate	0.35	0.15 to 0.4
	extensive	0.72	0.4 to 0.8
	complete	1.00	0.8 to 1.0

15.3.2.6 Communication Systems

In this subsection, damage ratios are presented for communication system central offices. Damage ratios for central offices are expressed as a fraction of the central office replacement cost.

The damage ratios for central offices are presented in Table 15.29. The damage ratios for a central office are evaluated as the sum of the damage ratios of all the subcomponents multiplied by their respective percentages of the total component (central office) value. The subcomponent information is presented in Table 15D.10 of Appendix 15D.

Table 15.29: Damage Ratios for Communication System Component

Classification	Damage State	Best Estimate Damage Ratio	Range of Damage Ratios
Central Office	slight moderate extensive complete	0.09 0.35 0.73 1.00	0.01 to 0.15 0.15 to 0.4 0.4 to 0.8 0.8 to 1.0

15.4. **References**

Applied Technology Council (1985). *Earthquake Damage Evaluation Data for California, ATC-13*, Applied Technology Council, Redwood City, CA.

G&E Engineering Systems, Inc., May 1994, "NIBS Earthquake Loss Estimation Methods, Technical Manual, Transportation and Utility Systems".

Howe, C.W., Cochrane, H.C. (1993), *Guidelines for the Uniform Identification, Definition, and Measurement of Economic Damages from Natural Hazard Events,* Institute of Behavioral Science, University of Colorado.

Jackson, P.L., Editor, *Means Square Foot Costs, (1994),* R.S. Means Company, Inc., Kingston, MA.

Phipps, M., et. al., 1992, Degenkolb Report on Effects of Loma Prieta Earthquake on Industry.

VSP Associates (1991), *A Benefit-Cost Model for the Seismic Rehabilitation of Hazardous Buildings, Volume 1, User's Manual, Volume 2, Supporting Documentation, FEMA 227 and 228,* Federal Emergency Management Agency, Washington, D. C.

Appendix 15A
Default Values for Regional Cost Variations

Construction costs vary significantly from one location to another. In order to account for this, the methodology provides default values for multipliers to be applied to the typical costs provided in Tables 15.2 through 15.4, which are based on national averages for materials and installation. These multipliers are shown in the Means Square Foot Cost publication as *Historical Cost Indices.* Means provides indices for a number of cities in each state (some of the smaller states have one or two cities only). This information, along with expert opinion, was used to develop default regional cost modifiers for each state in the United States. Since certain counties in each state can vary drastically from the state-wide average (e.g., San Francisco), county exceptions are provided for a limited number of counties.

Table 15A.1: State Cost Modifiers with County Exception

State		County Exceptions		Index
#	Name	#	Name	
01	Alabama			83.0
		01097	Mobile (Mobile)	87.5
02	Alaska			134.3
04	Arizona			92.8
		04013	Maricopa (Phoenix)	92.9
05	Arkansas			82.4
		05119	Pulaski (Little Rock)	84.1
06	California			116.9
		06075	San Francisco	132.7
		06037	Los Angeles	118.6
		06073	San Diego	113.6
08	Colorado			95.4
		08031	Denver	94.1
09	Connecticut			110.7
		09003	Hartford	111.2
10	Delaware			104.5
11	District of Colombia			98.9
12	Florida			90.1
		12095	Orange(Orlando)	90.7
13	Georgia			82.4
		13121	Fulton (Atlanta)	87.9
		13215	Muscogee (Columbus)	79.3
15	Hawaii			126.4
16	Idaho			94.1
		16001	Ada (Boise)	94.0
17	Illinois			100.3
		17031	Cook (Chicago)	111.0
		17167	Sangamon (Springfield)	97.0
		17197	Will (Joliet)	109.4
18	Indiana			94.4
		18089	Lake (Gary)	99.5
		18097	Marion (Indianapolis)	96.4
19	Iowa			92.3
		19113	Linn (Cedar Rapids)	92.6
		19153	Polk (Des Moines)	92.4
		19163	Scott (Davenport)	92.2

Table 15A.1: State Cost Modifiers with County Exception (continued)

State		County Exceptions		Index
#	Name	#	Name	
20	Kansas			89.1
		20177	Shawnee (Topeka)	91.8
21	Kentucky			91.8
		21111	Jefferson (Lousiville)	89.1
22	Louisiana			87.9
		22071	Orleans (New Orleans)	88.9
23	Maine			95.1
24	Maryland			95.8
25	Massachusetts			114.2
		25025	Suffolk (Boston)	125.6
26	Michigan			100.3
		26077	Kalamazoo	94.5
		26081	Kent (Grand Rapids)	89.1
		26163	Wayne (Detroit)	108.2
27	Minnesota			101.6
		27053	Hennepin (Minneapolis)	109.4
28	Mississippi			81.3
		28049	Hinds (Jackson)	80.8
29	Missouri			89.9
		29510	St. Louis City (St. Louis)	102.5
		29095	Jackson (Kansas City)	96.8
30	Montana			99.7
		30111	Yellowstone (Billings)	100.2
31	Nebraska			83.5
		31055	Douglas (Omaha)	90.3
32	Nevada			102.0
		32003	Clark (Las Vegas)	104.8
33	New Hampshire			97.8
34	New Jersey			111.5
		34013	Essex (Newark)	111.9
		34017	Hudson (Jersey City)	112.5
35	New Mexico			92.3
36	New York			102.7
		36061	New York (New York)	137.3
		36007	Broome (Binghampton)	98.1
			(Utica)	96.6
37	North Carolina			80.1
		37183	Wake (Raleigh)	80.3

Table 15A.1: State Cost Modifiers with County Exception (continued)

State		County Exceptions		Index
#	Name	#	Name	
38	North Dakota			87.5
39	Ohio			95.1
		39035	Cuyahoga (Cleveland)	104.1
		39153	Summit (Akron)	102.1
		39095	Lucas (Toledo)	100.5
		39023	Clark (Springfield)	89.4
40	Oklahoma			84.9
		40109	Oklahoma (Oklahoma City)	85.6
41	Oregon			109.4
		41051	Multnomah (Portland)	111.2
42	Pennsylvania			100.8
		42101	Philadelphia (Philadelphia)	110.2
		42075	Lebanon (Allentown)	106.3
		42049	Erie (Erie)	97.1
44	Rhode Island			110.5
45	South Carolina			79.4
		45019	Charleston (Charleston)	80.1
46	South Dakota			82.8
		46099	Minnehaha (Sioux Falls)	83.3
47	Tennessee			84.0
		47157	Shelby (Memphis)	88.8
48	Texas			84.6
		48201	Harris (Houston)	92.8
		48113	Dallas (Dallas)	89.4
		48245	Jefferson (Beaumont)	91.5
49	Utah			89.1
		49035	Salt Lake (Salt Lake City)	89.5
50	Vermont			89.3
51	Virginia			83.6
		51087	Henrico (Richmond)	86.4
		51013	Arlington (Alexandria)	93.9
53	Washington			107.6
		53033	King (Seattle)	110.1
54	West Virginia			95.4
		54039	Kanawha (Charleston)	94.3
55	Wisconsin			95.7
		55079	Milwaukee (Milwaukee)	99.4
56	Wyoming			84.3

Appendix 15B
Relationship Between Building Damage and Business Interruption

The subject of business and service interruption due to building damage has been identified for some time as an important contributor to indirect economic losses following earthquakes.

The issue of relating building damage to business interruption, and developing some statistical measures has been little researched, and available information is largely anecdotal. ATC-13 provided extensive coverage of the topic of building repair and loss of function, at the same time noting that:

" ... it is clear that there is a great variation in repair and demolition actions taken in connection with buildings that are moderately or severely damaged. There is also great variation for the loss of function associated with a given degree of damage.... The paucity of data currently available precludes describing loss of function based on statistical data from past events."

ATC-13 provided detailed tables with estimates of loss of function times for all the ATC-13 social classes of buildings (and all lifelines). These tables, which were developed by expert opinion, provided estimates of the time to restore 30%, 60%, and 100% of useability, for each of the six ATC-13 damage states.

Since ATC-13 was published, the information that relates building damage to loss of function continues to be unsystematic and anecdotal. A study of damage and loss of function for 14 industrial and administrative buildings in the Loma Prieta earthquake shows a typical wide spread of conditions and consequences (Phipps, et. al, 1992). Table 16A-1 summarizes some of the information from this study. It is possible that surveys of the recovery after the Northridge earthquake may provide some more systematic information on this issue.

Table 15B.1: Summary of Building Damage Vs Restoration Time: for 14 Industrial/Administrative Low-Rise Buildings, Loma Prieta Earthquake (Time in Days) (from Phipps, et. al., 1992)

#	Structure Type	Damage Percentage	Restoration Time (days)	Description of Damage
1	Tilt-up	2	5	roof-wall connections
2.	Steel	20	180	window wall cracked
3	Steel	2	1	piping, clogs
4	Steel	37	270	floor cracked
5	Steel	33	270	bracing buckled
6	Steel	32	270	bracing buckled
7	Steel	33	270	bracing buckled
8	Steel	NA	360	sprinklers
9	Steel	23	150	buckled bracing
10	Tilt-up	89	540	cracked walls
11	Tilt-up	60	90	failed roof
12	Precast	NA	90	wall-floor connections
13	Steel	42	180	asbestos
14	Steel	NA	21	radioactive contamination

Surveys of available information and experience suggest that the ATC-13 attempt to use expert opinion resulted in more apparent precision in estimating than was justified by the data. In addition, the attempt to provide 30%, 60% and 100% restoration estimates may be relevant for lifelines, but has little meaning for building function. Typical business and service facilities either provide something approaching 100% function in a fairly short time after the earthquake or cease to exist. Considerable improvisation and ingenuity is usually applied by management and staff to ensure rapid restoration .

Thus, this methodology presents a much simplified set of estimates, which it is felt match the current state of knowledge. In doing this, the distinction between the time needed for repair and the often much longer time needed for the whole repair project is recognized by multipliers applied to the extended construction time. In addition, the fact that business function can be to a large extent divorced from the building that housed it is also recognized by these multipliers. The latter situation might vary greatly among different kinds of business and users of the methodology may find it useful to discuss with key businesses in their area the functional consequences of building damage. It is also a reasonable supposition that businesses that have not experienced earthquake damage tend to overestimate its effect on their operation because it is hard for them to imagine emergency improvisation since they lack the experience.

Table 15B-2 shows a correlation between the **HAZUS** damage states and the ATC-13 estimates for functional restoration time: these may be compared with the estimates in

Tables 15.11, 15 .12 and 15.13. The ATC estimates assume that repair time is equivalent to restoration time.

Table 15B.2: ATC-13: Restoration Times Related to HAZUS Occupancies (Time in days) (ATC-13, 1985)

No.	Label	Occupancy Class	Damage State		
			Slight	**Moderate**	**Extensive**
		Residential			
1	RES1	Single Family Dwelling	3	11-72	72-146
2	RES2	Mobile Home	3	11-72	72-146
3	RES3	Multi Family Dwelling	3	11-72	72-146
4	RES4	Temporary Lodging	3	11-72	72-146
5	RES5	Institutional Dormitory	3	11-72	72-146
6	RES6	Nursing Home	3	11-72	72-146
		Commercial			
7	COM1	Retail Trade	20	71-202	202-347
8	COM2	Wholesale Trade	20	71-202	202-347
9	COM3	Personal and Repair Services	20	71-202	202-347
10	COM4	Professional/Technical Services	20	71-202	202-347
11	COM5	Banks/Financial Institutions	20	71-202	202-347
12	COM6	Hospital	56	156-338	338-613
13	COM7	Medical Office/Clinic	56	156-338	338-613
14	COM8	Entertainment & Recreation	20	71-202	202-343
15	COM9	Theaters	20	71-202	202-343
16	COM10	Parking	6	24-76	76-172
		Industrial			
17	IND1	Heavy	23	99-240	240-405
18	IND2	Light	23	99-240	240-405
19	IND3	Food/Drugs/Chemicals	16	72-235	235-380
20	IND4	Metals/Minerals Processing	22	99-248	248-405
21	IND5	High Technology	16	112-258	258-429
22	IND6	Construction	28	68-121	121-257
		Agriculture			
23	AGR	Agriculture	9	26-77	77-154
		Religion/Non-Profit			
24	REL	Church/Membership Organization	17	72-215	215-382
		Government			
25	GOV1	General Services	28	91-196	196-396
26	GOV2	Emergency Response	18	60-134	134-256
		Education			
27	ED1	Schools/Libraries	16	72-183	183-362
28	ED2	Colleges/Universities	16	72-183	183-362

Note: **HAZUS** Damage State

Slight	=	ATC #3: (CDF 5%)
Moderate: 30%,	=	between ATC 4-5 (20 - 45%)
Extensive 50%,	=	between ATC 5-6 (45 - 80%)

Appendix 15C
Derivation of Repair and Replacement Costs

The repair and replacement cost estimates in this document are derived from Means Square Foot Cost 1994, for Residential, Commercial, Industrial and Institutional Buildings

To arrive at these costs, the following procedure was used.

- A model building was selected from Means to represent each of the **HAZUS** NIBS Occupancy Classes. The Means identification number for the buildings chosen is shown in Table 15C.1.

- From the detailed cost and percentage for the selected model buildings the value for "Structure" was derived as follows: Means provides a percentage and value for "Superstructure" Means also provides cost estimate for "Foundations & Substructures". The "Structural" cost was estimated by adding the "Superstructure" costs and the "Foundations & Substructures" costs together.

- The Nonstructural component value was calculated by the following relationship:

  "Total Building Cost" - ["Superstructure Cost" + "Foundations & Substructures Cost"].

- Means provides a value for Total Building Cost: this is shown as "$Means/sq.ft" in Table 15C.1. This value is multiplied by 1.35 (the last column in Table 15C.1) to account for contractor's overhead and profit, design fees, and for additional post-earthquake costs including cleanup and demolition. Large additions to construction costs resulting from post-earthquake conditions are not assumed.

In Table 15C.2, the total costs for non-structural components shown in Table 15C.1 are allocated to Drift and Acceleration sensitive non-structural components in accord with the percentages noted in Section 15.2.1.1.

Table 15C.1: MEANS/NIBS Correlation and Cost Percentages

Class #	Label	Means ID #	Found./Subs. %	Structure %	Structure $ /sq. ft.	Means $ / sq. ft.	Total $ /sq. ft.
1	RES1	Av[1]	12	23	15	52	66
2	RES2	NA	0	25	11	NA	45
3	RES3	010	5	13	11	62	84
4	RES4	350	3	13	11	65	88
5	RES5	130	4	18	15	62	84
6	RES6	450	6	14	11	57	77
7	COM1	610	11	27	15	43	58
8	COM2	690	26	24	11	34	46
9	COM3	290	14	13	11	58	79
10	COM4	470	2	18	14	55	75
11	COM5	050	11	12	16	96	130
12	COM6	310	3	14	17	93	125
13	COM7	410	5	14	13	69	96
14	COM8	530	10	9	10	83	113
15	COM9	440	12	11	9	62	84
16	COM10	270	13	55	14	19	26
17	IND1	200	14	13	8	44	59
18	IND2	200	14	13	8	44	59
19	IND3	200	14	13	8	44	59
20	IND4	200	14	13	8	44	59
21	IND5	200	14	13	8	44	59
22	IND6	200	14	13	8	44	59
23	AGR	690[2]	36	26	6	16	22
24	REL	090	12	18	17	71	97
25	GOV1	670	12	16	12	57	76
26	GOV2	490	5	11	17	83	112
27	ED1	570	5	18	14	58	78
28	ED2	150	13	11	11	73	99

NOTES

1 Costs from Means *Average, 2 story residential* model

2 Agricultural costs based on Means #690 (warehouse) with steel frame, metal exterior cladding , no partitions/ceiling/finishes, no heating, electrical service only/no lighting, minimum reinforced slab on grade.

Table 15C.2: Non-structural Costs, Drift/Acceleration Ratios & Costs

Class #	Total $ / sq. ft.	NS %	Total NS $ / sq. ft.[1]	NS(Drift) %	NS (Drift) $ / sq. ft.	NS (Acc) %	NS (Acc) $ / sq. ft.
1	66	75	49	65	32	35	17
2	44	75	34	50	17	50	17
3	84	82	69	50	34	50	35
4	88	84	70	50	35	50	35
5	84	78	65	50	32	50	33
6	77	80	62	50	31	50	31
7	36	62	36	40	14	60	22
8	46	50	23	40	9	60	14
9	79	73	57	40	23	60	34
10	78	80	59	40	24	60	35
11	130	77	100	40	40	60	60
12	125	83	104	40	42	60	62
13	96	81	77	40	31	60	46
14	113	81	91	40	36	60	55
15	84	77	65	40	26	60	39
16	26	42	9	40	4	60	5
17	59	73	43	15	6	85	37
18	59	73	43	15	6	85	37
19	59	73	43	15	6	85	37
20	59	73	43	15	6	85	37
21	59	73	43	15	6	85	37
22	59	73	43	15	6	85	37
23	22	38	8	15	1	85	6
24	97	70	69	40	28	60	41
25	76	72	55	40	22	60	33
26	112	84	94	40	38	60	56
27	78	77	60	60	36	40	24
28	99	76	99	60	60	40	29

[1]Figure obtained by multiplying total cost by (100 - structural cost % - F&S cost %)/100

APPENDIX 15 D. Lifeline Subcomponent Information (Damage Ratios & Fraction of Value)

Table 15D.1. Subcomponents for the Railway System(G&E, 1994)

Sub-Component	Fraction of Total Component Value	Damage State	Damage Ratio
Fuel Facilities			
Electric Backup Power	2 %	slight moderate	0.20 0.70
Tanks	86 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Pump Building	2 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Horizontal Pumps	5 %	extensive	0.75
Electrical Equipment	5 %	moderate	0.50
Dispatch Facilities			
Electric Backup Power	30 %	slight moderate	0.20 0.70
Building	20 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Electrical Equipment	20 %	moderate	0.80
Railway Bridges			
Column		slight extensive complete	0.05 0.25 0.8
Abutment		slight moderate extensive	0.02 0.075 0.15
Connection		moderate extensive	0.01 0.02
Deck		slight	0.05

Table 15D.2. Subcomponents for DC Substations (G&E, 1994)

Subcomponent	Fraction of Total Component Value	Damage State	Damage Ratio
Building	35 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Equipment	65 %	moderate	0.80

Table 15D.3. Subcomponents for the Bus System (G&E, 1994)

Subcomponent	Fraction of Total Component Value	Damage State	Damage Ratio
Fuel Facilities			
Electric Backup Power	2 %	slight moderate	0.20 0.70
Tanks	79 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Building	11 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Pumps	4 %	extensive	0.75
Electrical Equipment	4 %	moderate	0.50
Dispatch Facilities			
Electric Backup Power	15 %	slight moderate	0.20 0.70
Building	30 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Electrical Equipment	55 %	moderate	0.80

Table 15D.4. Subcomponents for Port, Ferry and Airport Systems (G&E, 1994)

Sub-Component	Fraction of Total Component Value	Damage State	Damage Ratio
Port Fuel Facilities			
Electric Backup Power	5 %	slight moderate	0.20 0.70
Tanks	70 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Pump Building	5 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Horizontal Pumps	10 %	extensive	0.75
Electrical Equipment	10 %	moderate	0.50
Ferry Fuel Facilities			
Electric Backup Power	3 %	slight moderate	0.20 0.70
Tanks	72 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Pump Building	5 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Horizontal Pumps	10 %	extensive	0.75
Electrical Equipment	10 %	moderate	0.50
Airport Fuel Facilities			
Electric Backup Power	6 %	slight moderate	0.20 0.70
Tanks	64 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Pump Building	6 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Horizontal Pumps	12 %	extensive	0.75
Electrical Equipment	12 %	moderate	0.50

Table 15D.5. Subcomponent for Potable Water System Components (G&E, 1994)

Sub-Component	Fraction of Total Component Value	Damage State	Damage Ratio
Water Treatment Plant			
Electric Backup Power	4 %	slight moderate	0.20 0.70
Chlorination Equipment	4 %	slight moderate	0.15 0.50
Sediment Flocculation	12 %	slight moderate	0.20 0.50
Chemical Tanks	20 %	slight moderate	0.20 0.75
Electric Equipment	30 %	moderate	0.60
Elevated Pipe	10 %	extensive complete	0.65 0.90
Filter Gallery	20 %	complete	1.00
Wells			
Electric Backup Power	16 %	slight moderate	0.20 0.70
Well Pump	34 %	extensive	0.75
Building	16 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Electric Equipment	34 %	moderate	0.60
Pumping Plants			
Electric Backup Power	16 %	slight moderate	0.20 0.70
Pumps	34 %	extensive	0.75
Building	16 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Electrical Equipment	34 %	moderate	0.60

Table 15D.6. Subcomponets for Waste Water Treatment (G&E, 1994)

Subcomponents	Fraction of Total Component Value	Damage State	Damage Ratio
Electric Backup Power	5 %	slight moderate	0.20 0.70
Chlorination Equipment	3 %	slight moderate	0.15 0.50
Sediment Flocculation	36 %	slight moderate extensive	0.20 0.50 0.80
Chemical Tanks	7 %	slight moderate	0.20 0.75
Electrical/ Mechanical Equipment	14 %	moderate	0.60
Elevated Pipe	8 %	extensive complete	0.65 0.90
Buildings	27 %	complete	1.00

Table 15D.7 Subcomponents for Crude & Refined Oil Systems(G&E, 1994)

Sub-Component	Fraction of Total Component Value	Damage State	Damage Ratio
Refineries			
Electric Backup Power	3 %	slight moderate	0.20 0.70
Electrical/ Mechanical Equipment	6 %	moderate	0.60
Tanks	42 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Stacks	42 %	extensive	0.80
Elevated Pipe	7 %	complete	1.00
Pumping Plants			
Electric Backup Power	30 %	slight moderate	0.20 0.70
Pump	20 %	extensive	0.75
Building	20 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Electrical/ Mechanical Equipment	30 %	moderate	0.60
Tank Farms			
Electric Backup Power	6 %	slight moderate	0.20 0.70
Electrical/ Mechanical Equipment	24 %	moderate	0.60
Tanks	58 %	slight moderate extensive complete	0.20 0.40 0.85 1.00
Elevated Pipes	12 %	extensive complete	0.65 0.90

Table 15D.8. Subcomponents for Electrical Substations (G&E, 1994)

Classification	Fraction of Total Component Value	Damage State	Damage Ratio
Transformers	68 %	extensive complete	0.50 1.00
Circuit Breakers	26 %	slight moderate extensive complete	0.17 0.33 0.67 1.00
Disconnect Switches	3 %	slight moderate extensive complete	0.17 0.42 0.67 1.00
Current Transformers	3 %	extensive complete	0.67 1.00

Table 15D.9. Subcomponents for Generation Plant (G&E, 1994)

Subcomponents	Fraction of Total Component Value	Damage State	Damage Ratio
Electrical Equipment	17 %	slight moderate	0.30 0.60
Boilers & Pressure Vessels	19 %	moderate	0.50
Vertical vessels	5 %	moderate extensive	0.50 0.80
Pumps	9 %	extensive	0.75
Horizontal vessels	14 %	complete	1.00
Large motor operated valves	5 %	complete	1.00
Boiler Building	17 %	slight moderate extensive complete	0.10 0.40 0.80 1.00
Turbine Building	14 %	slight moderate extensive complete	0.10 0.40 0.80 1.00

Table 15D.10. Subcomponents for Communication Centers (G&E, 1994)

Subcomponents	Fraction of Total Component Value	Damage State	Damage Ratio
Electric Power (Backup)	15 %	slight moderate	0.20 0.70
Switching Equipment	49 %	slight moderate extensive complete	0.05 0.20 0.60 1.00
Building	36 %	slight moderate extensive complete	0.10 0.40 0.80 1.00

Chapter 16
Indirect Economic Losses

16.1 Introduction

This Chapter is written with several goals in mind. First, it is intended to familiarize the reader with the concept of indirect loss, including a brief discussion of input-output models, the traditional approach for tracing interindustry ripple effects (Sections 16.2 and 16.3).

Second, an algorithm for addressing supply shocks (the engine of the Indirect Loss Module) is developed and explained. Section 16.4 develops a method for computing indirect losses, one that addresses the effects of supply and demand disruptions. The Indirect Loss Module is a computational algorithm which accounts for earthquake induced supply shortages (forward linkages) and demand reductions (backward linkages). The module is a version of a computable general equilibrium model designed to rebalance a region's interindustry trade flows based on discrepancies between sector supplies and demands. The flowchart of the overall methodology, highlighting the Indirect Loss Module and its relationship to other modules is shown in Figure 16.1.

Third, the chapter discusses data requirements and operational issues related to running the module for different levels of analysis. Section 16.5 provides an overview of input data, module operation, and results output in a Default or User-Supplied Data Analysis. It also includes suggestions for approaches to conducting a Advanced analysis.

Finally, a number of experiments are reported to assist the user in interpreting the Module’s results. Section 16.6 analyzes how patterns of direct damage, preexisting economic conditions (unemployment, import-export options, and economic structure) and external assistance alter indirect loss. Example solutions based on the Northridge earthquake are provided, along with the results of Monte Carlo simulations. The former is provided to illustrate how the model can be applied, the latter to suggest the wide range of possible outcomes. Lastly, a set of helpful observations are presented.

16.2 What are Indirect Losses?

Earthquakes may produce dislocations in economic sectors not sustaining direct damage. All businesses are forward-linked (rely on regional customers to purchase their output) or backward-linked (rely on regional suppliers to provide their inputs) and are thus potentially vulnerable to interruptions in their operation. Such interruptions are called indirect economic losses. Note that these losses are not confined to immediate customers or suppliers of damaged enterprises. All of the successive rounds of customers of customers and suppliers of suppliers are impacted. In this way, even limited earthquake physical damage causes a chain reaction, or ripple effect, that is transmitted throughout the regional economy.

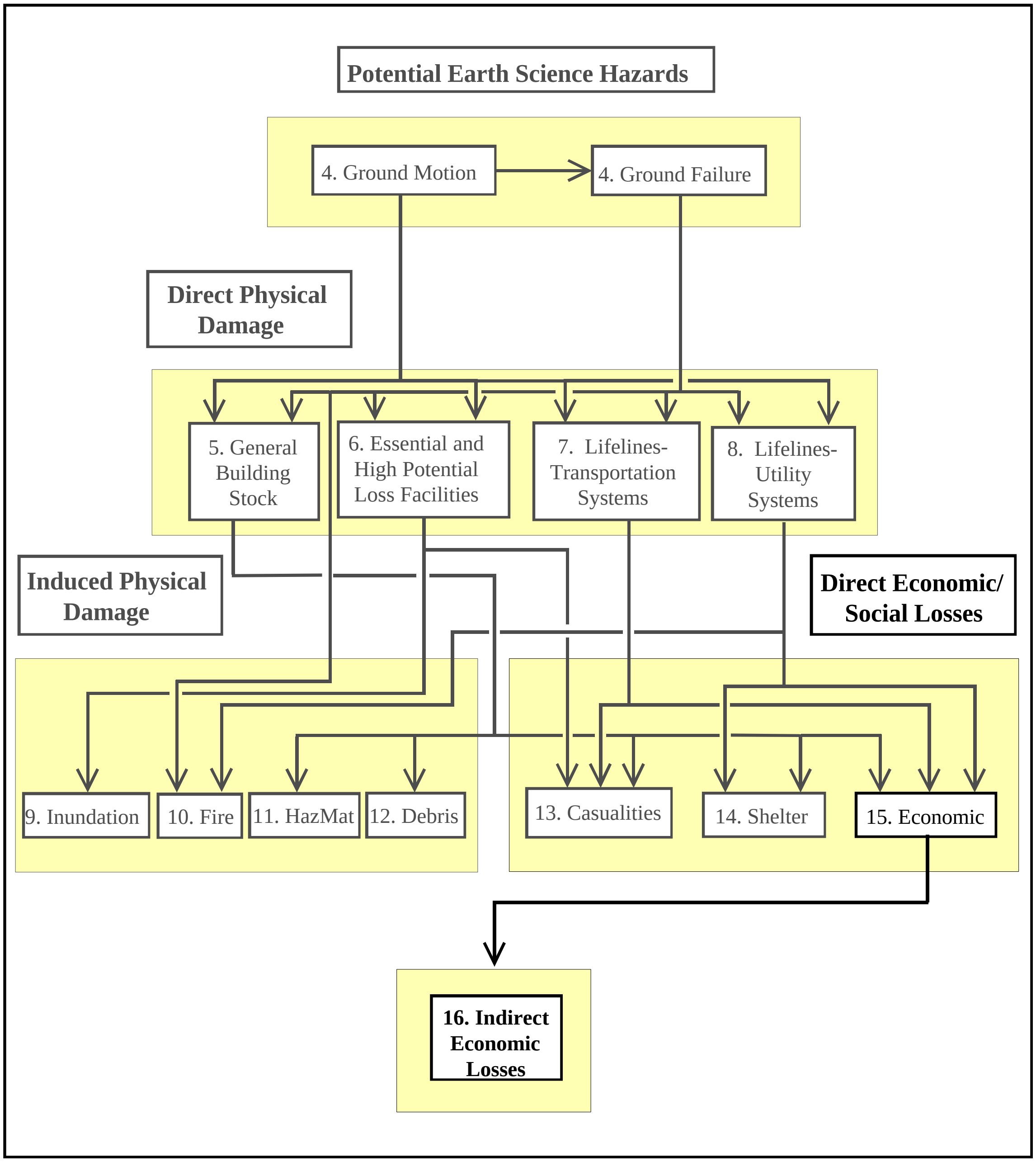


Figure 16.1 Indirect Loss Estimation Relationship to Other Modules in the Earthquake Loss Estimation Methodology

The extent of indirect losses depends upon such factors as the availability of alternative sources of supply and markets for products, the length of the production disturbance, and deferability of production. Figure 16.2 provides a highly-simplified depiction of how direct damages induce indirect losses. In this economy firm A ships its output to one of the factories that produce B, and that factory ships to C. Firm C supplies households with a final product (an example of a final demand, FD) and could also be a supplier of intermediate input demand to A and B. There are two factories producing output B, one of which is destroyed in the earthquake. The first round of indirect losses occurs because: 1) direct damage to production facilities and to inventories cause shortages of inputs for firms needing these supplies (forward-linked indirect loss); 2) damaged production facilities reduce their demand for inputs from other producers (backward-linked indirect loss); or 3) reduced availability of goods and services stunt household, government, investment, and export demands (all part of final demand).

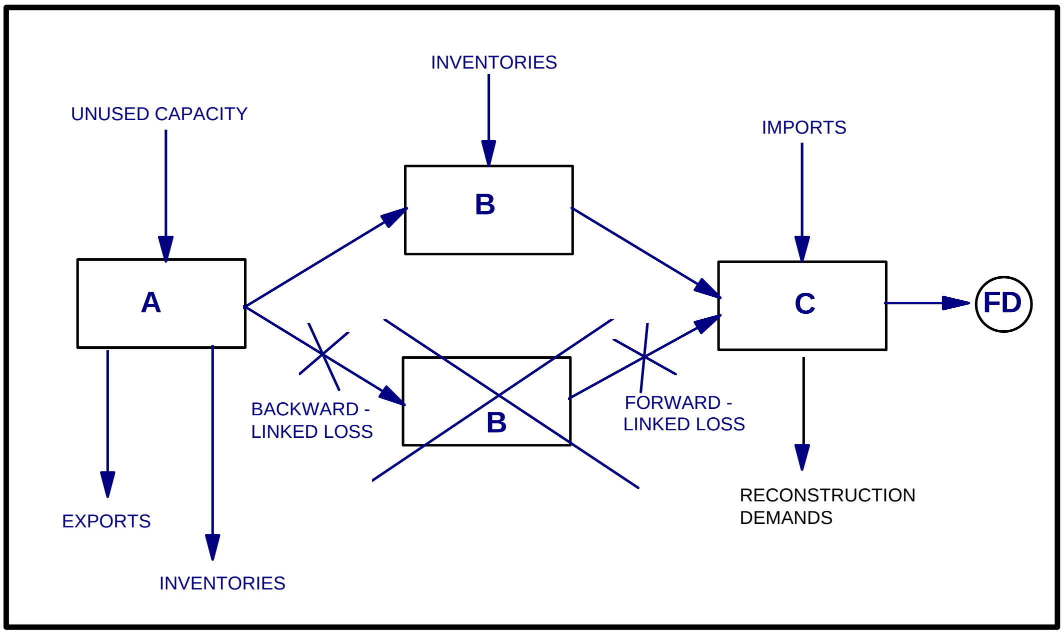


Figure 16.2 Indirect Losses and Adjustments to Lessen Them

16.2.1 Supply Shortages and Forward Linked Losses

The supply shortages caused as a result of reduced availability of input B could cripple factory C, if C is unable to locate alternative sources. Three options are possible: 1) secure additional supplies from outside the region (imports); 2) obtain additional supplies from the undamaged factory (excess capacity); and 3) draw from B's unsold stock of output (inventories). The net effect of diminished supplies are referred to as forward-linked losses, the term forward (often referred to as downstream) implying that the impact of direct damages is shifted to the next stage or stages of the production process.

16.2.2 Demand Effects and Backward Linked Losses

Disasters can also produce indirect losses if producer and consumer demands for goods and services are reduced. If, in the example provided in Figure 16.2, firm B has a reduced demand for inputs from A, then A may be forced to scale back operations. As in the case of forward-linked losses, the affected firms may be able to circumvent a weakened market, in this case by either finding alternative outlets such as exports or building up inventory.[1]

The higher rate of unemployment caused by direct damages and subsequent indirect factory slowdowns or closures would reduce personal income payments and could cause normal household demands to erode. However, it is more likely that the receipt of disaster assistance, unemployment compensation, or borrowing, would buoy household spending throughout the reconstruction period. Evidence from recent events (Hurricanes Andrew and Hugo, the Loma Prieta Earthquake and the Northridge Earthquake) confirms that normal household demands are only slightly altered by disaster in the short-run. As a result of this observation, the Indirect Loss Module discussed below delinks household incomes and demands.

16.2.3 Regional vs. National Losses

It has sometimes appeared that natural disasters tend to stimulate employment and revitalize a region. Clearly, the generous federal disaster relief policies in place after the 1964 Alaskan earthquake, the 1971 San Fernando earthquake, and Hurricane Agnes in 1972, served to buoy the affected economies, thereby preventing the measurement of significant indirect losses. <u>From a regional accounting stance</u>, it appeared that the net losses were inconsequential. However, this viewpoint fails to take into account the cost of disasters on both household and federal budgets.

Some, if not most, public and private post-disaster spending is unfunded; that is, it is not paid for out of current tax revenues and incomes. In the case of households this amounts to additional indebtedness which shifts the burden or repayment to some future time period. Federal expenditures are not budget neutral either. As in the case of households, governments cannot escape the financial implications of increased spending for disaster relief. Either lower priority programs must be cut, taxes raised, or the federal debt increased. The first two options simply shift the reduction in demand and associated indirect damages to other regions. Projects elsewhere may be canceled, services curtailed, and/or household spending diminished as after-tax incomes shrink. The debt option provides no escape either, since it, too, places the burden on others, e.g., a future generation of taxpayers.

From a national accounting stance, indirect losses can be measured by deriving regional indirect impacts, adjusted for the liability the Federal government incurs in providing

[1]Building up inventory is not a permanent solution, since eventually the inventories have to be sold. Firms may be willing to do so on a temporary basis, hoping that market conditions will improve at a later date.

disaster relief, and for offsetting increases in outputs elsewhere. The positive effects outside aid produces for the region are to some degree offset by negative effects produced by the three federal budget options. Since it is impossible to know *a priori* which option the federal government will utilize, it is safest to assume that the two effects cancel, i.e., that the positive outcomes from federal aid are offset by the negative national consequences caused by the budget shortfall.

Since the primary user of the Loss Estimation Methodology is likely to be the local entity involved in seismic design and zoning decisions, the Indirect Loss Module is designed accordingly. That is, it adopts a local accounting stance. One simplistic approach to obtaining a national measure of net loss would be to exercise the Loss Module excluding outside federal assistance.

16.3 Interindustry Models

Input-output techniques are widely utilized to assess the total (direct plus higher-order) economic gains and losses caused by sudden changes in the demand for a region's products. Higher demand for rebuilding and a lower demand for tourism, for example, lend themselves to traditional input-output I-O methods. This technique is relatively simple to apply and is already in widespread use in state and local agencies, though not necessarily those associated with emergency management. However, input-output models compromise realism, primarily in the area of supply bottlenecks. Although the Indirect Loss Module addresses both supply and demand shocks in a more sophisticated manner, it is based on the same foundation as the input-output model—a region's interindustry input requirements. Because the two approaches share a common base, we begin by introducing the principles underlying input-output analysis, with an emphasis on demand disturbances, and then extend the framework to accommodate supply shocks.

Input-output analysis was first formulated by Nobel laureate Wassily Leontief and has gone through several decades of refinement by Leontief and many other economists. At its core is a static, linear model of all purchases and sales between sectors of an economy, based on the technological relationships of production. Input-output (I-O) modeling traces the flows of goods and services among industries and from industries to household, governments, investment, and exports. These trade flows indicate how much of each industry's output is comprised of its regional suppliers' products, as well as inputs of labor, capital, imported goods, and the services of government. The resultant matrix can be manipulated in several ways to reveal the economy's interconnectedness, not only in the obvious manner of direct transactions but also in terms of dependencies several steps removed (e.g., the construction of a bridge generates not only a direct demand for steel but also indirect demands via steel used in machines for its fabrication and in railroad cars for its transportation).

The very nature of this technique lays it open to several criticisms: the models are insensitive to price changes, technological improvements, and the potential for input substitution at any given point in time. However, even with these limitations, I-O techniques are a valuable guide for the measurement of some indirect losses. A very brief technical review is provided for those readers who may be unfamiliar with interindustry modeling.[2]

16.3.1 A Primer on Input-Output Techniques

The presentation is restricted to a simple three industry economy. The shipments depicted as arrows in Figure 16.2 are represented as annual flows in Table 16.1. The *X*'s represent the dollar value of the good or service shipped from the industry listed in the left-hand heading to the industry listed in the top heading. The *Y*'s are shipments to consumers (goods and services), businesses (investment in plant and equipment and retained inventories), government (goods, services and equipment), to other regions (exported goods and services). The *V*'s are the values-added in each sector, representing payments to labor (wages and salaries), capital (dividends, rents, and interest), natural resources (royalties and farm rents), and government (indirect business taxes). The *M*'s represent imports to each producing sector from other regions.

A basic accounting balance holds: total output of any good is sold as an intermediate input to all sectors and as final goods and services:

$$X_A = X_{AA} + X_{AB} + X_{AC} + Y_A \qquad (16\text{-}1)$$

Rearranging terms, the amount of output available from any industry for final demand is simply the amount produced less the amount shipped to other industries.

[2] Input-output and "interindustry" are often used synonymously because of the emphasis in I-O on the sectoral unit of analysis, mainly comprised of producing industries. Strictly speaking, however, interindustry refers to a broad set of modeling approaches that focus on industry interactions, including activity analysis, linear programming, social accounting matrices, and even computable general equilibrium models. Most of these have an input-output table at their core. The reader interested in a more complete understanding of I-O analysis is referred to Rose and Miernyk (1989) for a brief survey; Miller and Blair (1985) for an extensive textbook treatment; and Boisvert (1992) for a discussion of its application to earthquake impacts. For other types of interindustry models applied to earthquake impact analysis, the reader is referred to the work of Rose and Benavides (1997) for a discussion of mathematical programming and to Brookshire and McKee (1992) for a discussion of computable general equilibrium analysis.

Table 16.1 Intersectoral Flows of a Hypothetical Regional Economy (dollars)

To From	A	B	C	Final Demand	Gross Output
A	x_{AA}	x_{AB}	x_{AC}	Y_A	x_A
B	x_{BA}	x_{BB}	x_{BC}	Y_B	x_B
C	x_{CA}	x_{CB}	x_{CC}	Y_C	x_C
V	V_A	V_B	V_C		
M	M_A	M_B	M_C		
Gross Outlay	x_A	x_B	x_C	Y	X

To transform the I-O accounts into an analytical model, it is then assumed that the purchases by each of the industries have some regularity and thus represent technological requirements. Technical coefficients that comprise the structural I-O matrix are derived by dividing each input value by its corresponding total output. That is:

$$a_{AA} = \frac{X_{AA}}{X_A}; \qquad a_{AB} = \frac{X_{AB}}{X_B}; \qquad a_{AC} = \frac{X_{AC}}{X_C}; \qquad (16\text{-}2)$$

The a's are simply the ratios of inputs to outputs. An a_{AB} of 0.2 means that 20 percent of industry B's total output is comprised of product A.

Equation (16-1) can then be written as:

$$X_A = a_{AA} X_A + a_{AB} X_B + a_{AC} X_C + Y_A \qquad (16\text{-}3)$$

In matrix form Equation (16-3) is:

$$X = AX + Y \qquad (16\text{-}4)$$

To solve for the gross output of each sector, given a set of final demand requirements, we proceed through the following steps:

$$(I - A)X = Y \qquad (16\text{-}5)$$

$$(I - A)^{-1}Y = X \qquad (16\text{-}6)$$

The term $(I - A)^{--1}$ is known as the Leontief Inverse. It indicates how much each sector's output must increase as a result of (direct and indirect) demands to deliver an additional unit of final goods and services of each type. It might seem that a $1 increase in the final demand for product A would result in the production of just an additional $1 worth of A. However, this ignores the interdependent nature of the industries. The production of A requires ingredients from a combination of industries, A, B, and/or C. Production of B, requires output from A, B, and/or C, and so on. Thus, the one dollar increase in demand for A will stimulate A's production to change by more than one dollar. The result is a multiple of the original stimulus, hence, the term "multiplier effect" (a technical synonym for ripple effect).

Given the assumed regularity in each industry's production requirements, the Leontief Inverse need only be computed once for any region (at a given point in time) and can then be used for various policy simulations reflected in changes in final demand (e.g., the impact of public sector investment) as follows:

$$(I - A)^{-1} DY = DX \tag{16-7}$$

More simply, the column sums of the Leontief Inverse are sectoral multipliers, *M*, specifying the total gross output of the economy directly and indirectly stimulated by a one unit change in final demand for each sector. This allows for a simplification of Equation (16-7) for cases where only one sector is affected (or where one wishes to isolate the impacts due to changes in one sector) as follows:[3]

$$M_A DY_A = DX \tag{16-8}$$

Under normal circumstances final demand changes will alter household incomes and subsequently consumer spending. Thus, under some uses of input-output techniques, households (broadly defined as the recipients of all income payments) are "endogenized" (included within the *A* matrix) by treating it as any other sector, i.e., a user (consumer) of outputs and as a supplier of services. An augmented Leontief inverse is computed and yields a set of coefficients, or multipliers, that capture both “indirect” (interindustry) and subsequent “induced” (household income) effects. Multipliers are computed from a matrix with respect to households. These are referred to as Type II multipliers in contrast to the Type I multipliers derived from the “open” I-O table, which excludes households. Of course, since they incorporate an additional set of spending linkages, Type II multipliers are larger than Type I, typically by around 25%.

[3] Note that the previous discussion pertains to demand-side (backward-linked) multipliers. A different set of calculations is required to compute supply-side (forward-linked) multipliers. (Computationally, the structural coefficients of the supply-side model are computed by dividing each element in a given row by the row sum.) Though mathematically symmetric, the two versions of the model are not held in equal regard. There is near universal consensus that demand-side multipliers have merit because there is no question that material input requirements are needed directly and indirectly in the production. However, the supply-side multipliers have a different connotation—that the availability of an input stimulates its very use. To many, this implies the fallacy of “supply creates its own demand.” Thus, supply-side multipliers must be used with great caution, if at all, and are not explored at length here. For further discussion of the conceptual and computational weaknesses of the supply-side model, see Oosterhaven (1988) and Rose and Allison (1988).

Note also that the multipliers discussed thus far pertain to output relationships. Multipliers can also be calculated for employment, income, and income distribution effects in analogous ways. Also note that sectoral output multipliers usually have values of between 2.0 and 4.0 at the national level and are lower for regions, progressively shrinking as these entities become less self-sufficient and hence the endogenous cycle of spending is short-circuited by import leakages. Sectoral output multipliers for Suffolk County, the core of the Boston Metropolitan Statistical Area, are for the most part in the range of 1.5 to 2.0.

16.3.2 An Illustration of Backward Linked Losses

Conventional input-output models provide a starting point for measuring indirect damages that are backward-linked, providing that the disaster does not significantly alter the region's input patterns and trade flows. In the next section, we will discuss modifications of the methodology for such changes. The calculation of indirect damages for the more simple case is illustrated in the following example beginning with the input-output transactions matrix presented in Table 16.2.

Table 16.2: Interindustry Transactions

To From	A	B	Households	Other Final Demand	Gross Output
A	20	45	30	5	100
B	40	15	30	65	150
Households	20	60	10	10	100
Imports	20	30	30	0	80
Gross Outlay	100	150	100	80	430

This simplified transactions table is read as follows: $20 of industry A's output is used by itself (e.g., a refinery uses fuel to transform crude oil into gasoline and heating oil). $45 of output A is shipped to industry B. $30 is marketed to the household sector and $5 is sold to government, used in investment, or exported to another region. $20 worth of household services is required to produce $100 of output A, and $60 is needed for $150 of B. According to the table, 30 percent of the consumer's gross outlay is allocated to the purchase of A, 30 percent to B, 10 percent to household services, and 30 percent to imports.

Assume that the input-output tables shown above represent a tourist-based seaside economy. Industry A represents construction while B represents tourism. What would happen to this economy if an earthquake destroyed half the region's beachside hotels? <u>Direct</u> economic losses are comprised of manmade assets destroyed in the earthquake plus the reductions in economic activity[4] in the tourist sector. Assume that the damage to hotels influences some tourists to vacation elsewhere the year of the disaster, reducing the annual $95 million demand for hotel accommodations by $45 million.

For the purposes of this illustration, household spending and demands are linked. Therefore, a Type II multiplier would be utilized to assess the income and output changes

[4] Economic activity can be gauged by several indicators. One is Gross Output (sales volume). Another is Value-Added, or Gross National Product (GNP), which measures the contribution to the economy over and above the value of intermediate inputs already produced, thereby avoiding double-counting (note the "Gross" in GNP simply refers to the inclusion of depreciation and differs from double-counting meaning of the term in Gross Output.) Specifically, Value-Added refers to returns to primary factors of production: labor, capital, and natural resources. The concept is identical to the oft used term National Income, which is numerically equal to GNP.

anticipated. The effect of declining tourism on the region's economy is easily derived from the initial change in demand and the Type II multipliers presented in Figure 16.3. Each tourist dollar <u>not</u> spent results in a loss of \$1.20 and \$2.03 worth of production from A and B, respectively.

The resultant total (direct plus indirect) decline in regional household income is \$1.17 per tourist dollar lost (row 3 column 2 of the closed Leontief Inverse). If nothing else changed (including no pick up in construction activity), the regional income lost for the year is \$52.65 million (\$45 million times 1.17). Of this total, \$18 million (40 cents of lost income for each tourist dollar lost, or .4 times \$45 million) is directly traceable to the disaster, while the other \$34.65 million in regional income loss represents indirect income losses cause by reduced demands for intermediate goods and consumer items via backward interindustry linkages and normal household spending.

TOTAL COEFFICIENTS
(TYPE II MULTIPLIER)

$$(I-A)^{1-} = \begin{array}{c} \begin{array}{ccc} \text{CONSTRUCTION} & \text{TOURISM} & \text{HOUSEHOLD} \end{array} \\ \begin{bmatrix} 2.12 & 1.20 & 1.11 \\ 1.29 & 2.03 & 1.11 \\ 1.04 & \boxed{1.17} & 1.85 \end{bmatrix} \end{array}$$

x \$45 MILLION
= \$52.65 MILLION
DIRECT, INDIRECT, INDUCED INCOME LOSSES

DIRECT COEFFICIENTS

$$A = \begin{array}{c} \begin{array}{ccc} \text{CONSTRUCTION} & \text{TOURISM} & \text{HOUSEHOLD} \end{array} \\ \begin{bmatrix} .2 & .3 & .3 \\ .4 & .1 & .3 \\ .2 & \boxed{.4} & .1 \end{bmatrix} \end{array}$$

x \$45 MILLION
= \$18 MILLION
DIRECT INCOME LOSSES

SECONDARY INCOME LOSS	= \$52.65 MILLION	minus	\$18 MILLION
	= \$34.65 MILLION		

Figure 16.3 Illustrative Computation

16.3.3 The Impact of Outside Reconstruction Aid on the Region and the Nation

Negative effects would be countered by the stimulative impact of state and federal disaster aid and insurance settlements. Whether these positive forces completely offset the negatives produced by the reduction in tourist trade hinges on the magnitude of the direct effects and the associated multipliers for these two activities. Assume, for example, that \$50 million of outside reconstruction funds pour into the community in the first year. The Type II income multiplier for the construction industry is 1.04. The net regional income loss the year of the disaster is, therefore: ($50 million x 1.04) - ($45 million x 1.17), or a net loss of $0.65 million.

Indirect income changes in this case are very significant and can be computed as the difference of total income impacts and direct income impacts. We know from the direct coefficients matrix that household income changes directly by 20 and 40 cents, respectively, for each dollar change in construction and tourist expenditures. The net indirect regional impact from the reduction in tourism, and the aid program are therefore: ($50 x 1.04 - $50 x .2) - ($45 x 1.17 - $45 x .4), or a net gain of $7.35 million.

This is what the region loses; however, national impacts are quite different. The $50 million of federal assistance injected into the region must be paid for either by cutting federal programs elsewhere, raising taxes, or borrowing. Each option impacts demand and outputs negatively. Although it is unlikely that they will precisely offset the gains the region enjoys, it is safe to assume that they will be similar in magnitude. If so, indirect losses from a national perspective is the net regional loss <u>with the positive effects from federal aid omitted</u>. The national net income loss will then remain $52.65 million.

The foregoing analysis was limited to the year of the disaster and presupposed that unemployed households did not dip into savings or receive outside assistance in the form of unemployment compensation, both of which are often the case. In terms of the summation of impacts over an extended time horizon, results do not significantly change if alternative possibilities are introduced. For example, if households choose to borrow or utilize savings while unemployed or to self-finance rebuilding, future spending is sacrificed. Therefore, even though an unemployed household may be able to continue to meet expenses throughout the reconstruction period, long-term levels of expenditure and hence product demand, must decline.

In the preceding analysis, indirect losses were derived from demand changes only. This approach lends itself to events in which supply disruptions are minimal, or where sufficient excess capacity exists. A different method is required when direct damage causes supply shortages. The Indirect Loss Module, to which we now turn, modifies the basic I-O methodology to accommodate both supply and demand disruptions.

16.4 The Indirect Loss Module

The foregoing example illustrated how <u>*demand*</u> shocks filter through the economy to produce indirect losses. As indicated, supply shocks require a different treatment. Most <u>*supply*</u> shock models begin with the same trading pattern which produced the A matrix and subsequent multipliers inherent in the input-output method. However, once damage to buildings and lifelines constrain the capacity of each economic sector to ship its output to other sectors, or receive shipments, the trading patterns have to be readjusted. There are several ways to accomplish this. The simplest (Cochrane and Steenson, 1994) is to estimate how much each sector's output will decline as a result of direct damage and then address how the resultant excess demands and/or supplies will be filled and or disposed of. In the event that the sum of all interindustry demands and final demands exceed the post-disaster constraint on production, then available imports and inventory changes could temporarily help to rebalance the economy. In some sectors excess supplies might exist. If so, inventories may be allowed to accumulate or new markets might be found outside the affected region. Surviving production is reallocated according to the interindustry direct coefficients matrix until all sector excess supplies and demands are eliminated. At this point, a new level of regional output, value added and employment is computed and contrasted with the levels observed prior to the disaster. The difference between these levels approximates indirect loss.[5]

16.4.1 Damage -- Linkage to the Direct Loss Module

The Indirect Economic Loss module is linked to preceding modules through three channels in which damage, the direct shock, is introduced. First, building damage causes a certain degree of loss of function to each sector, forcing them to cut output. A vector of loss of function by industry in the first year of the disaster provides a set of constraints to the Indirect Loss module that is related to the general building stock damage levels. Loss of function is based upon the time needed to clean up and repair a facility or to rent an alternative facility to resume business functions (see Section 15.2.4). Loss of function is calculated for each occupancy class. Table 16.3 links the sectors in the Indirect Loss Module to the occupancy classes in the Direct Loss Module. Loss of function associated with lifeline disruption is not evaluated.

Table 16.3 NIBS Occupancy Classes and Indirect Loss Module Economic Sectors

Direct Loss Module	Indirect Loss Module
IND3	Agriculture (Ag)
NONE	Mining (Mine)
IND6	Construction (Cnst)
IND 1,2,3,4,5 (AVG.)	Manufacturing (Mfg)
COM3	Transportation (TRANS)
COM 1,2 (AVG.)	Trade (Trde)
COM 5,4 (AVG.)	Finance, Insurance and Real Estate (FIRE)
(COM 2,4,6,7,8,9; RES 4,6; REL; ED 1,2) (AVG.)	Service (Serv)
GOV1	Government (Govt)
NONE	Miscellaneous (Misc)

Second, post-disaster spending on reconstruction, repair and replacement of damaged buildings and their contents causes a stimulus effect in the Indirect Loss Module. This stimulus is based on the total dollar damage to buildings and contents. Third,

[5]This approach relies on both the existence of regional input-output tables and several assumptions regarding: inventory management, importability of shortages, exportability of surpluses and the amount of excess capacity existing in each sector. It does not accommodate the effects of relative price changes on final demands, nor does it entertain the degree to which labor and capital are substitutable in the underlying production functions. Treatment of these issues require a more sophisticated approach, one which is discussed in the literature under the topic heading Computable General Equilibrium (CGE) Systems.

reconstruction inputs for transportation and utility lifeline damage also provide a stimulus effect to the module.

Total levels of reconstruction expenditures are equivalent to damage estimates, but two modifications are needed before they can be incorporated into the analysis. One modification is the timing of the reconstruction in terms of weeks, months, or years after the earthquake. The distribution of reconstruction expenditures over time is discussed in Section 16.5.1.1 in relation to user inputs to the module.

The other modification is the itemization of expenditures by type (plant, equipment, etc.) so that this spending injection is compatible with the economic model used to determine indirect effects. The input-output (I-O) model at the core of the module disaggregates the economy into sectors according to one-digit Standard Industrial Classification (SIC) codes. The brunt of the reconstruction expenditures will be assigned to Manufacturing and Construction sectors.

One idiosyncrasy of the I-O model is the role of Wholesale and Retail Trade and of Transportation. These sectors are based on the concept of a "margin," i.e., the cost of doing business (labor, insurance, electricity, gasoline, office supplies) plus profits, but does not include the items sold or shipped (which are merely a pass-through in any case).[6] Those expenditures assigned to Construction require no adjustment, but when spending on manufactured goods is inserted into the model, portions of the total should be assigned to the Wholesale/Retail Trade sector and to the Transportation sector. For very large items bought directly from the factory, there is no Trade sector activity, but for smaller items (e.g., office equipment, trucks), the adjustment is necessary. Generally, the Wholesale margin is 80%. Whether purchased from the factory or from the Trade sector, the Transportation margin is always applicable and is typically equal to 20%.

A similar adjustment is necessary in nearly all cases for consumer spending for replacement of contents. In this case, it is more appropriate to use the Retail Trade margin of 80%. Again, the Transportation margin of 20% would be applicable to purchases of larger items.

In cases where the margin adjustment is required, the user simply applies the following formulas:

$$\frac{\Delta L}{1+tm} = \Delta Y_M \tag{16-9}$$

$$\Delta L - \Delta Y_M = \Delta T \tag{16-10}$$

[6]The reason for this device is that many items are sold through wholesale and retail outlets and transported commercially, and, if included as "inputs" to these sectors, the linkage between buyers and sellers would be lost, i.e., it would appear that most purchases were from Wholesale/Retail Trade or Transportation, as if these sectors produced most items in the economy.

where:

ΔL = Portion of loss estimate (reconstruction/replacement) to which margin adjustment applies.

ΔY_M = Manufacturing expenditures after margin adjustment.

ΔT = Retail/wholesale, trade or transportation expenditures.

tm = Retail/wholesale, trade or transportation margin.

16.4.2 Supply-Side Adjustments and Rebalancing the Economy

The Indirect Loss Module is a computational algorithm that utilizes input-output coefficients to reallocate surviving production. The algorithm computes post-event excess demands and supplies. It rebalances the economy by drawing from imports, inventories, and idle capacity when supplies are constrained. It allows for inventory accumulation, production for export (to other regions) and sales to meet reconstruction needs in the event that normal demands are insufficient to absorb excess supplies The process of reallocation is governed by the amount of imbalance detected in each of the economy's sectors. Rebalancing is accomplished iteratively by adjusting production proportionately until the discrepancy between supplies and demands is within a tolerable limit.[7] A simple schematic of the process is provided in Figure 16.4.

[7]The tolerable limit is the degree to which the solution values vary from one iteration to the next.

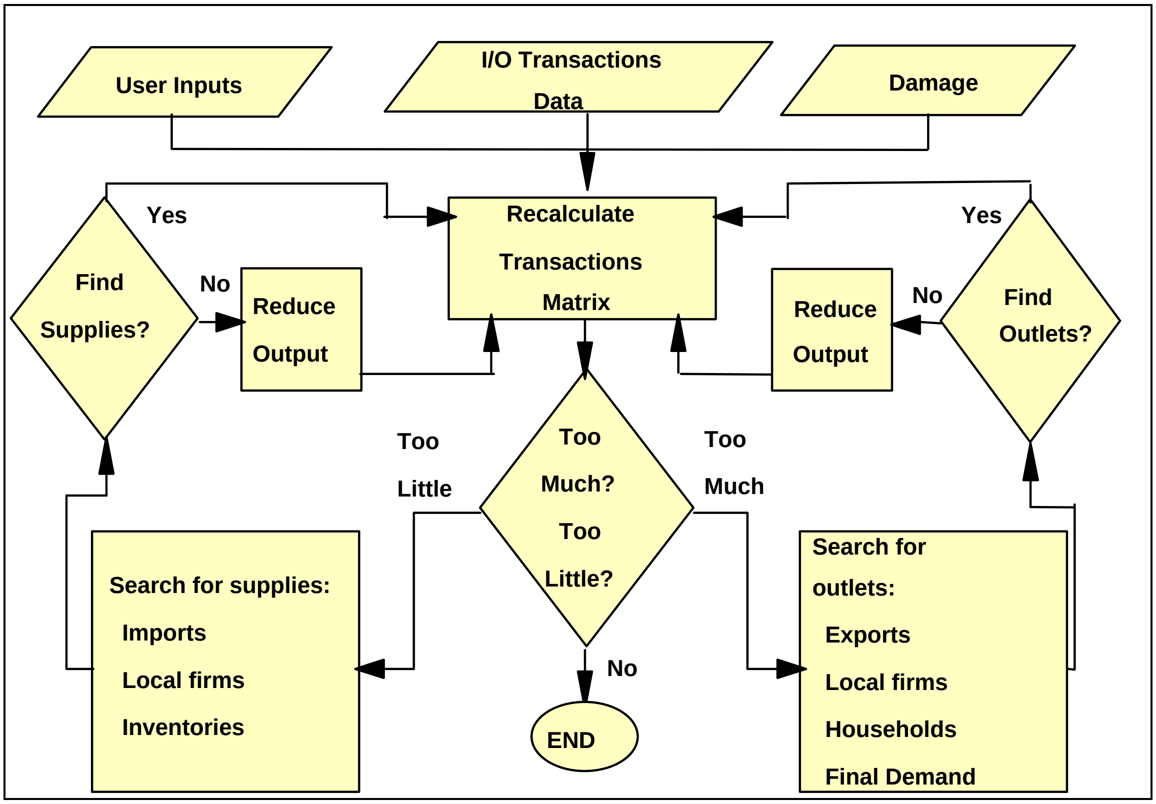


Figure 16.4 Indirect Loss Module Schematic

This section illustrates how the model adjusts to supply-side constraints when a disaster causes disruption in the level and pattern of local production.

Table 16.4 illustrates a simple economy with three industries: construction, manufacturing, and trade. There are also two rows for payments to households from those industries and imports which those industries require, plus two columns that represent household demands and exports. Households make no purchases from other households. All amounts in the table are in dollars. In the economy's initial state, the row and column sums are equal.

Table 16.4 Initial Transactions

From/To	Constr	Mfg	Trade	HH	Export	Sum
Constr	10	30	20	20	35	115
Mfg	20	20	10	30	80	160
Trade	15	20	5	40	5	85
HH	30	40	20			90
Import	40	50	30			120
Sum	115	160	85	90	120	

Table 16.5 shows how the economy changes due to the direct impact from a disaster. In this case, there is a 10% loss of manufacturing output as the result of damage to manufacturing facilities. Corresponding to this loss, both the purchases and sales of the

manufacturing sector fall by 10%, as reflected in the row and column sums. The transactions directly affected are highlighted in bold type in the table. A new column, named "Lost HH," has been added to this table to reflect manufacturing output that is unavailable to households because of the earthquake.

Table 16.5 10% Direct Loss in Manufacturing

From/To	Constr	**Mfg**	Trade	HH	Export	Sum	Lost HH
Constr	10	**27**	20	20	35	112	
Mfg	**18**	**18**	**9**	**27**	**72**	**144**	**3**
Trade	15	**18**	5	40	5	83	
HH	30	**36**	20			86	
Import	40	**45**	30			115	
Sum	113	**144**	84	87	112		

Table 16.6 illustrates the first example of the indirect response to this situation. This is a "fully-constrained" economy, characterized by no more than 2% unemployment, 0% import replacement, 0% inventory availability or replacement, and 0% additional exports. This means that there are no ways for manufacturers to replace inputs that were disrupted by the disaster.

Under these circumstances, construction and trade firms must cut their previous manufacturing by 10%. There is full employment in the local economy, meaning that other firms in manufacturing cannot increase output to meet the desired purchases by construction and trade. Further imports are not allowed, and there are no inventories of manufacturing output to use. Construction and trade firms, faced with an irreplaceable 10% loss in manufactured goods have no choice but to reduce their production by 10%. The net result is that the 10% direct loss in manufacturing translates into a 10% loss throughout the entire economy. Portions of the table affected by indirect loss are highlighted in italics. The row and column sums are once again in balance. Household consumption is decreased for all three sectors, and there is no way to make up for it.

Table 16.6 Response to Loss with Fully Constrained Economy

From/To	Constr	**Mfg**	Trade	HH	Export	Sum	Lost HH
Constr	*9*	**27**	*18*	*18*	*31.5*	*103.5*	*2*
Mfg	**18**	**18**	**9**	**27**	**72**	**144**	**3**
Trade	*13.5*	**18**	*4.5*	*36*	*4.5*	*76.5*	*4*
HH	*27*	**36**	*18*			*81*	
Import	*36*	**45**	*27*			*108*	
Sum	*103.5*	**144**	*76.5*	*81*	*108*		

The fully constrained economy is an extreme case, and most economies are characterized by some flexibility, or slack, so that inputs can be replaced and outputs can be sold. We illustrate this by raising the potential level of additional imports by 10%, and the potential level of additional exports by 40%. This is insufficient to ensure that construction and trade can acquire the supplies they need to meet local demands and sell products that are no longer being bought by manufacturing.[8] Sectors not suffering direct losses return to their pre-event levels of production.[9] Manufacturing might import additional manufactured inputs where needed to replace its own direct losses, but labor is not available due to the low unemployment rate and the assumption that the temporarily unemployed labor in manufacturing will not be available to other firms in the sector. Manufacturing losses will only be replaced as damaged manufacturing facilities return to production.

In Table 16.7, the underlined values show where the important changes have occurred. Both construction and trade were allowed to import the manufactured inputs they lost as a result of the earthquake. Also, construction and trade exported that portion of their output that manufacturing no longer purchased. Because of these two factors, there is no indirect loss in the case illustrated in Table 16.7.

The same results may be obtained in other ways. Instead of increasing imports, there might be some unemployment in the local economy. In this case, other firms in the manufacturing sector could hire some of the unemployed resources to make up the shortfall. Alternatively, there might be inventories of manufactured goods, either at the manufacturers or in storage at the construction and trade firms that require those goods. On the output side, firms faced with a reduction in purchases from the manufacturing sector may decide to continue production and store the resulting product in inventory until the disrupted facilities are back in production or until they can find new export markets.

Table 16.7 Response to Loss with Relaxed Import and Export Constraints

From/To	Constr	**Mfg**	Trade	HH	Export	Sum	Lost HH
Constr	*10*	**27**	*20*	*20*	*<u>38</u>*	*115*	
Mfg	**18**	**18**	**9**	**27**	**72**	144	**3**
Trade	*15*	**18**	*5*	*40*	*<u>7</u>*	*85*	
HH	*30*	**36**	*20*			*86*	
Import	*<u>42</u>*	**45**	*<u>31</u>*			*118*	
Sum	*115*	144	*85*	*87*	*117*		

In Table 16.7, manufacturing remains at its immediate post-disaster level because the situation being illustrated is immediately after the event, before reconstruction can take place. If the slack in the system came from unemployment instead of imports, the results would be different. That portion of the manufacturing sector undamaged by the earthquake could hire additional resources and make up the direct losses. Overall production would regain its pre-disaster levels. Therefore, unlike the example illustrated

[8] Construction only needs to increase its level of imports by 2, 5% of its initial imports of 40, and trade only requires an increase in imports of 1, or 3.3% of 30. Construction requires additional exports of 3, or 8.6% of original exports. The limiting sector is trade, required to find export markets for 2 units, 40% of the 5 units it originally exported.

[9] Even if the slack assumptions are set higher, the algorithm limits sectoral production to be no higher than prior to the earthquake (unless there is a positive counter-stimulus from, say, reconstruction activity).

which shows no net indirect change, there would be a net indirect increase in sales that would be equal to the direct loss, making for a net economic change of zero.

Tables 16.6 and 16.7 show an important way in which this algorithm departs from traditional I-O analysis. The technical coefficients for both Tables are different from those of the original economy. This is because imports and exports have been allowed to replace lost supplies and sales in the system. The usual technical coefficients in an I-O table assume that the relationships between imports and intermediate inputs are fixed, as well as assuming that the relationships between exports and intermediate outputs are fixed. Though these assumptions are convenient for the purposes of I-O analysis, they are a departure from reality in general, and especially so in emergency situations. Also note, from Table 16.7, that the household and import/export sectors are no longer balanced in terms of row and column sums. This is due to the short-run nature of the problems being solved in the model. In the longer run, households must repay their borrowing, and exports must rise to repay the short-run imports, unless government disaster aid or some other form of external financing is used to pay for the short-run consumption and imports.

Tables 16.6 and 16.7 illustrate the two extremes that the model can reflect in responding to pure supply-side disruptions. In its fully functional implementation, the model adjusts simultaneously for multiple shocks of varying amplitude in any number of sectors, while also accounting for demand-side (final demand) increases that typically accompany disasters.

16.4.3 The Time Dimension

The model is evaluated at various levels of temporal resolution for the fifteen (15) year period following the earthquake. For the first two (2) months after the earthquake, weekly time intervals are used. Between two (2) months and twenty four (24) months, the economy is evaluated on a monthly basis. From two (2) years to fifteen (15) years, the economy is evaluated annually. It is made dynamic by considering how industry loss of function is restored and reconstruction expenditures are made over the time windows. Thus while the inputs to the Indirect Economic Loss module differ with each time interval, the rebalancing algorithm for the economy and adjustment factors (e.g., availability of supplemental imports to make up for lost production) do not change. The time patterns of functional restoration and reconstruction are user inputs and are discussed in Section 16.5.

16.4.4 The Effects of Rebuilding and Borrowing

Borrowing impacts the model in that future demands are reduced in proportion to the temporal payments for rebuilding. In the case of Northridge this amounted to less than 50 percent. Federal assistance and insurance settlements provided the bulk of the financial resources for reconstruction. The importance of refinancing lies in longer-term effects of repayment. If the affected region receives no assistance then the stimulative effects of rebuilding are only temporary. The region will eventually have to repay loans and future spending will suffer. This is accounted for in the model as follows.

1. It is assumed that all loans mature 15 years *from the time of the earthquake*. Therefore, the first year's loans are for 15 years. The second year's loans are for 14 years, and so on.
2. Tax implications are ignored. Interest is not tax deductible.
3. Borrowing costs are assumed to be 6 percent. This is a real interest rate (inflation free). The discount rate is assumed to be 3 percent. It too is inflation free.

The loan payments are computed as follows (Table 16.8).

Table 16.8 Annual Borrowing Costs

Year	1	2 through 15
Annual Payment	$\left[\frac{r}{(1-(1+r)^{(-15+1)})}\right] loan1$	$\left[\frac{r}{(1-(1+r)^{(-16+t+1)})}\right] loan_t + Pay_{t-1}$
Explanation	loan 1 times the annual payment factor (r is real interest)	payment from t-1 plus loan t times the annual payment factor

Future demands are reduced by the annual payments times the percentage households spend on each sector’s output. For example, if households are paying back $50 million in year 1 then spending from all categories decline as shown in the following table. The second column in Table 16.9 is the pre-disaster spending pattern. For example, 0.2

percent of household income was spent on agricultural products; 24.6 percent was spent on services. This percentage times $50 million loan repayment cost yields the reduction in household spending by sector in year 1.

Table 16.9 The Effect of Loan Repayment on Household Demands

Sector	Household Spending (% spent on each sector)	Reduced Demand in $ millions (% times loan payment)
Ag	0.2%	0.08
Mine	0.0%	0
Cnst	11.2%	5.59
Mfg	7.5%	3.75
Trns	6.2%	3.08
Trde	21.6%	10.82
FIRE	23.2%	11.59
Serv	24.6%	12.3
Govt	5.3%	2.63
Misc	0.3%	0.15

Exercising the module sequentially using average values over the reconstruction period derives time dependent indirect losses.

16.4.5 The Issue of Aggregation

Study regions may consist of single counties, higher levels of aggregation such as several counties comprising a metropolitan area, or lower levels of aggregation such as a group of contiguous census tracts. In principal, the methodology underlying the Indirect Economic Loss module is applicable regardless of the level of aggregation. However, its accuracy is likely to be greater for study regions that represent cohesive economic regions, often called "trading areas" (e.g., cities or metropolitan areas) than for those at lower levels of aggregation because of the ability of the core Input-Output model to meaningfully represent the region's economic structure. Furthermore, in evaluating regional employment impacts, the module requires input data on the number of jobs located within the study region -- that is, data on employment by place of work rather than by place of residence. While this information can be obtained at the county level, its availability and reliability at lower levels of aggregation are much more problematic. Similar problems are associated with other input data such as unemployment rates. More generally, the user should also be aware that some of the input assumptions to the model (such as the availability of alternate markets) are related to the study region's level of aggregation. By adjusting the nature of the economy and the linkage to surrounding regions, the analyst can get a "ball park" estimate of what the real indirect losses and gains might be. Tracing the effects to a specific geographic area (beyond that directly impacted by the earthquake) is problematic. Section 16.5 below provides some discussion of appropriate input data and assumptions to the module.

16.5 Running the Module

This section describes operational issues related to the methodology's Indirect Economic Loss module, including data inputs, the operation of the software module, and the format and interpretation of the output. Default Data Analysis utilizes primarily default data and requires minimal user input. In User-Supplied Data Analysis, while the same types of data are required, the user provides information specific to the economy of the study region and the disaster being modeled. Advanced Data and Models analysis assumes expert participation and may involve expanding the module framework or applying alternative frameworks.

16.5.1 Default Data Analysis Inputs, Operation and Output

16.5.1.1 User Inputs and Default Data

Running the Indirect Economic Loss module requires a number of user inputs. While default values are provided for all of these inputs, as discussed below, it is advisable even in a Default Data Analysis to override certain of them with data for the study region where available. Table 16.10 describes the inputs required and their default values.

HAZUS™ provides default values for the current employment based on Dun & Bradstreet data and income levels for the region based on County Business Pattern data. Note that in contrast to some other sources of regional employment data, this estimate of workers represents the number of persons who work within the study region, rather than the number of employed persons who reside there. Employment by place of work is appropriate in this type of analysis because the model will estimate job loss within the study region due to physical damage there from the disaster. It is recommended that the Default Data Analysis user review the default values provided and replace them if more accurate or recent data is available. Note that in User-Supplied Data Analysis, where a user-provided IMPLAN Input-Output table is used instead of a synthetic table, the current employment and income levels are read in from the IMPLAN files and override the default values.

The type or composition of the economy, together with the employment level, is used by the module to automatically select a synthetic Input-Output transactions table to represent the study region economy. Default Data Analysis utilizes a synthetic transactions table aggregated from three basic classes of economies: 1) primarily manufacturing, 2) primarily service, secondarily manufacturing, and 3) primarily service, secondarily trade. These 3 archetypical economies represent approximately 90 percent of the 113 transactions tables used to construct the three synthetic tables. Each type is broken into four size classifications: super (greater than 2 million in employment), large (greater than 0.6 million but less than 2 million), mid range (greater than 30 thousand but less than .6 million) and low (less than 30 thousand). Appendix 16A provides examples of regions in each type and size class. While type 1 (manufacturing) is the default, the user should revise this as appropriate. Appendix Tables A2, A3, and A4 can be used as a guide.

Supplemental imports, inventories (demands), inventories (supplies), and new export markets represent available channels for excess supply or demand that can help reduce the bottleneck effects in the post-disaster economy. As mentioned above, appropriate values depend in part on the level of aggregation of the study region. Default values are set at 0 for inventories supply and demand for all industries. Default values for imports and exports are set at values considered appropriate for a “distinct” or self-contained study region such as a metropolitan area. The default values are presented, together with discussion of how they can be modified in a User-Supplied Data Analysis, in Section 16.5.2.2.

The supplemental imports variable, due to limitations on available data, needs further explanation. Data on the amount of imports per sector are available only in the aggregate. For any one sector in the economy, the total amount of intermediate products imported is known, but the amount of these imports that comes from any individual sector is not known. The amount of new imports that may be allowed must be set to a very small level. Otherwise, the amount of products that may be imported will almost always replace any intermediate goods lost from local suppliers, and no indirect output losses will be observed. The level of supplemental imports also needs to be kept low because of factor homogeneity problems. There will be cases when there are no substitutes for locally obtained intermediate goods. In such cases, allowing imports would unreasonably eliminate indirect losses. Being conservative in the amount of imports allowed helps avoid both of these problems. The default values for imports have been tested in the model, and are felt to yield realistic results.

Table 16.10 User **Supplied Inputs for Indirect Economic Module**

Variable	Definition	Units[a]	Default Value
Current Level of Employment	The number of people gainfully employed, by place of work (not residence).	Employed persons	Region-specific
Current Level of Income	Total personal income for the study region.	Million dollars	Region-specific
Composition of the Economy (Default Data Analysis only)	1. Primarily manufacturing 2. Primarily service, secondarily manufacturing. 3. Primarily service, secondarily trade.	1, 2, or 3	1
Supplemental Imports	In the event of a shortage, the amount of an immediate product unavailable from local suppliers which may be obtained from new imports.	Percent of current total current annual imports (by industry)	Defaults for “distinct region”
Inventories (Supplies)	In the event of a shortage, the amount of a good that was supplied from within a region that can be drawn from inventories within the region.	Percent of annual sales (by industry)	0 (for all industries)
Inventories (Demand)	In the event of a surplus, the amount of a good placed in inventory for future sale.	Percent of current annual sales (by industry)	0 (for all industries)
New Export Markets	In the event of a surplus, the amount of a good which was once sold within the region that is now exported elsewhere.	Percent of current annual exports (by industry)	Defaults for “distinct region”
Percent Rebuilding	The percent of damaged structures that are repaired or replaced	Percent	95%

Unemployment Rate	The pre-event unemployment rate as reported by the U.S. Bureau of Labor Statistics	Percent	6%
Outside Aid/Insurance	The percentage of reconstruction expenditures that will be financed by Federal/State aid (grants) and insurance payouts.	Percent	50%
Interest Rate	Current market interest rate for commercial loans.	Percent	5%
Restoration of function	The percent of total annual production capacity that is lost due to direct physical damage, taking into account reconstruction progress.	Percent (by industry, by time interval for 5 years)	Defaults for moderate-major event
Rebuilding (buildings)	The percent of total building repair and reconstruction that takes place in a specific year.	Percent (by time interval for 5 years)	70% (yr.1), 30% (yr.2)
Rebuilding (lifelines)	The percent of total transportation and utility lifeline repair and reconstruction that takes place in a specific year.	Percent (by time interval for 5 years)	90% (yr.1), 10% (yr.2)
Stimulus	The amount of reconstruction stimulus anticipated in addition to buildings and lifelines repair and reconstruction.	Percent (by industry, by Time interval for 5 years)	0% (for all)

Notes: (a) Percent data should be entered as percentage points, e.g. 60 for 60%.
(b) **HAZUS** provides a default value for the counties in the study region.
(c) See Section 16.5.2.2.

The variables for percent rebuilding, unemployment rate, percent outside aid, and interest rate all influence how the economy is expected to react to the disaster, in particular the reconstruction stimulus, the available slack or unused capacity in the economy, and the associated indebtedness that would be incurred from reconstruction financing. The user is recommended to revise the unemployment and interest rates as appropriate. However, all of these variables can be adjusted for purposes of "what-if" scenario modeling. For example, how would regional indirect economic losses change if only 20 percent of reconstruction was financed by sources outside the region such as insurance or federal disaster aid?

Parameters for functional restoration, as well as rebuilding for both buildings and lifelines, are associated with the anticipated speed of reconstruction and recovery. To specify functional restoration, user inputs are required for the percent of each industry's production capacity that is lost as a result of physical damage in each year for the first 5 years after the disaster. Default parameters are provided that are designed to be consistent with a "moderate-to-major" scale of disaster. These parameter values and suggestions for modifying them in a User-Supplied Data Analysis are provided in Section 16.5.2.2 below.

In terms of rebuilding, the module requires user inputs as to the percent of total rebuilding expenditures for buildings and lifelines respectively that are expected to be made in each of the first 5 years following the disaster. Table 16.11 provides an example. Note that the total dollar amount required to fully rebuild damaged and destroyed public and private capital is provided by the Direct Economic Loss module. The percent of this total that is actually rebuilt is specified by the user input on "percent rebuilding" and may be less than 100 percent if not all of the damage is repaired or replaced. The annual percents for rebuilding buildings and lifelines as shown in Table 16.11 provide the timeline over which the reconstruction expenditures are made and should therefore sum to 100 percent over the 5-year period.

Table 16.11 Rebuilding Expenditures Example

Year	1	2	3	4	5	Total
% of Total Rebuilding Expenditures (Buildings)	70	30	0	0	0	100
% of Total Rebuilding Expenditures (Lifelines)	90	10	0	0	0	100

Reconstruction speed is also to a large extent related to the scale of the disaster. In general, lifeline reconstruction is expected to proceed much more quickly than building reconstruction, as has been the experience in previous disasters. For a Default Data Analysis, default parameters are provided that are designed to be consistent with a "moderate-to-major" scale of disaster. Modifying these parameters would be appropriate in a User-Supplied Data Analysis, and guidelines are provided in Section 16.5.2.2 below. These parameters can also be adjusted in Default Data Analysis for purposes of "what-if" scenario modeling for faster or slower paces of reconstruction.

The additional reconstruction stimulus parameters can also be adjusted for "what-if" evaluations.

16.5.1.2 Calculation of Indirect Loss

A direct shock is introduced into the Indirect Loss Module by adjusting the outputs and purchases in proportion to a sector's loss of function. Restrictions on shipments (forward linkages) and purchases (backward linkages) are computed and the resultant excess demands or supplies are derived. See Figure 16.5. The sample transactions table provided in Table 16.20 (Section 16.6.2) is used to illustrate. The first two rows above the table indicate the total direct shock and associated indirect losses, which are initially zero. The first round effects are simply the direct loss of function times the inputs to that sector (backward links) and shipments from that sector (forward links). In the event of a 30 percent loss of function in the transportation sector, for example, demand for manufactured goods would fall by 15.6 (0.3 times 51.9). The remainder of the column effects is computed similarly.

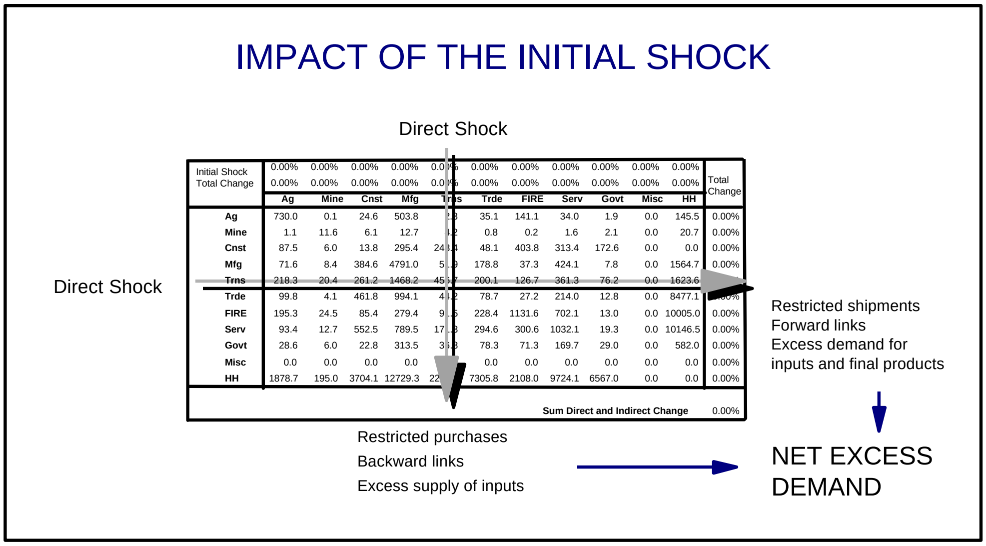


Figure 16.5 Initial Effects of the Shock

The same 30 percent shock would limit shipments to other sectors; finance, insurance, and real estate, for example, will initially receive 38.0 less (0.3 times 126.7) in services from transportation.

These first round effects produce excess demands and supplies that trigger a search for markets and alternative supply sources.

In building the model, several critical choices had to be made regarding post-event household spending patterns, labor mobility, elasticity of supplies from the construction industry, and the potential for product substitutions due to relative price changes. Evidence from previous disasters (summarized in the User's Manual) suggests that: 1) normal spending patterns are not significantly altered; 2) the workforce is highly mobile, particularly in the construction sector; and 3) relative prices do not change appreciably. Therefore, labor and construction sales are not constrained, and normal household spending is fixed and independent of current income. Given these conditions, the model assesses the net excess supplies (output less the sum of intermediate and final demands). A positive net value implies an excess supply; a negative indicates excess demand. It then attempts to resolve sectoral imbalances through a series of adjustments. If excess demand is detected, the algorithm checks to see if sufficient capacity exists in a sector. Excess capacities are a function of user defined level of unemployment and is calculated within the model using the following equation.

$$AC = 2.36 \times (UR - .02) \qquad (16\text{-}11)$$

Where:

AC is available production capacity and expressed as a percentage (measured as a decimal) of the pre-event capacity

UR is the unemployment rate (e.g., .05).

If idle capacity is insufficient to meet excess demand then the model explores the potential of importing and/or drawing down inventories. These options are also provided by the user and are expressed as a percent of pre-event capacities.

Disposal of excess supplies is logically similar. Two options, inventory accumulation and exports, are explored. As in the case of the previous options, both are expressed as a percentage and are determined by the user. In most cases excess supplies are not critical to the model's, operation, particularly when reconstruction spending looms large. Much of the excesses are drawn into the rebuilding process.

After completing the first iteration of output adjustments, the algorithm recalculates the intermediate supplies and demands and then reinvestigates the adjustment options previously explored. Outputs are revised in proportion to the amount each sector is out of balance. A moving average of previously attempted outputs is used to initialize each iteration's search. The search is terminated once the sum of the absolute sectoral output differences diminishes to a specified level; the default is set at .00001.

Indirect income loss is calculated as using the following formula.

$$\sum_{t=1}^{T} \sum_{i=1}^{j} \frac{(td_{i,t} - dd_{i,t})Y_i}{(1+r)^t} \tag{16-12}$$

where: $td_{i,t}$ is the total percent reduction in sector i income during period t.
Y_t is income of sector i.
$dd_{i,t}$ is the direct percent reduction in sector i income during period t.
r is the real interest rate to discount the indirect losses
j is the number of sectors

dd is computed in the model by multiplying the initial sectoral income by the respective loss of function. The variable td is the total percentage reduction in income caused by the combination of direct loss and forward and backward linked losses. The difference between the two is then the percentage reduction in income attributable to indirect effects. The difference is pure indirect loss. This percentage when multiplied by sectoral incomes yields indirect income lost. A similar formula to Equation 16-12, without discounting, is used to evaluate indirect employment loss.

16.5.1.3 The Format of the Output

The module produces two summary reports on the results. The first, whose layout is indicated in Table 16.12, shows the percent and level of indirect economic impact for the study region economy in terms of employment and income effects. Note that impacts may be either losses (negative numbers) or gains (positive numbers). Results are given by time interval for the first 5 years. Average figures are also provided for years 6 to 15 and for the entire 15-year post-disaster period of analysis. All incomes are discounted at the rate of 3 percent. In the case of income, Year 6 to Year 15 losses or gains are discounted to the present. Employment loss or gains are shown as numbers of workers.

Table 16.12 Summary Tables for Indirect Economic Impact

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6 to 15	Average
% Net Indirect Employment Impact							
% Net Indirect Income Impact							
Net Indirect Employment Impact							
Net Indirect Income Impact in Millions $							

The second summary table breaks down the net indirect employment and income impacts by the 10 major industries. Differences in impacts and recovery trends typically are very significant between industries, in part because much of the gains from the reconstruction stimulus accrues to the construction industry (and to some extent the manufacturing and trade industries).

It is important to note that to get a complete picture of the economic impact of the disaster, both the direct and indirect economic losses or gains should be considered.

16.5.2 User-Supplied Data Analysis

This level of Analysis differs from the Default Data level of analysis in two main respects: (1) interindustry trade flows, as represented in the Input-Output model of the economy, and (2) specification of restoration and rebuilding parameters. Rather than selecting from built-in synthetic Input-Output transactions tables, the user should obtain specific tables for the study region from a standard source, the Minnesota IMPLAN Group. In terms of specifying restoration and rebuilding parameters, the user can replace the built-in data with suggested parameter “packages” appropriate to the disaster being modeled. In addition, other parameters such as the availability of supplementary imports can also be modified.

16.5.2.1 IMPLAN Input-Output Data

HAZUS requires three files from the IMPLAN input-output data set (the asterisk in each of the following file names refers to the IMPLAN model name. Therefore, a model for Jackson County would produce a file named JACKSON.402):

- *.402 This is the transactions matrix.
- *.403 This is a file of final demands information.
- *.404 This is a file of final payments information.

Details regarding the operation of the IMPLAN program and the construction of these files can be obtained from the technical documentation for the system. IMPLAN is currently sold and supported by the Minnesota IMPLAN Group; the Group can be reached at:

Minnesota IMPLAN Group, Inc. (MIG)
1940 S. Greeley, Suite 201
Stillwater, MN 55082
Voice 612-439-4421 FAX 612-439-4813
e-mail linda003@maroon.tc.umn.edu

Software and data for any county in the United States can be obtained from the IMPLAN group. When requesting data, regions can also be defined by specifying a zip code aggregation.

The user can either request the three data files for the study region from MIG or obtain the software and database to construct the files. In the former case, the user should specify that the required industry aggregation scheme is essentially a one-digit Standard Industrial Classification (SIC) grouping that maps detailed IMPLAN industries into the ten industry groups used in the methodology. Table 16.13 describes the correspondence between IMPLAN and **HAZUS™** industry classes.

Table 16.13 Industry Classification Bridge Table

IMPLAN	**HAZUS**
1-27	AG (Agriculture)
28-47	MINE (Mining)
48-57	CNST (Construction)
58-432	MFG (Manufacturing)
433-446	TRNS (Transportation)
447-455	TRDE (Trade)
456-462	FIRE (Finance, Insurance and Real Estate)
463-509	SERV (Service)
510-523	GOVT (Government)
524	MISC (Miscellaneous)

If the user obtains the IMPLAN software, the three data files can be constructed by following the instructions and constructing an aggregated Input-Output account using an existing or built-in template for 1-digit SIC classification.

16.5.2.2 Specifying Indirect Loss Factors

In addition to applying IMPLAN Input-Output data for the study region, a User-Supplied Data Analysis can involve adjusting module parameters to more closely fit the study region and disaster being modeled. Parameter sets and selection algorithms are suggested below for both the four indirect loss “factors” -- supplemental imports, new export markets, inventories supply, and inventories demand -- and industry restoration and rebuilding.

As previously noted in the Default Data Analysis discussion, availability of supplemental imports and new export markets is related in part to the size or level of aggregation of the study region and its geographic situation. A single county making up part of a large metropolitan area would have a much higher new import/export capacity (i.e., to neighboring counties) than would a single-county city that was geographically a distinct urban area and at some distance from other urban areas. Table 16.14 suggests two possible sets of factor values for geographically “distinct” and “component” study regions based on expert opinion.

Table 16.14 Suggested Indirect Economic Loss Factors
(percentage points)

	Distinct Region				Component Region			
Industry	Imports	Inv. Supply	Inv. Demand	Exports	Imports	Inv. Supply	Inv. Demand	Exports
AGR	5	0	0	20	6	0	0	35
MINE	5	0	0	30	6	0	0	45
CON	999	0	0	10	999	0	0	25
MFG	4	1	1	30	6	1	1	45
TRNS	2	0	0	0	4	0	0	0
TRDE	3	1	1	0	5	1	1	0
FIRE	3	0	0	0	5	0	0	0
SVC	3	0	0	0	5	0	0	0
GOVT	3	0	0	0	5	0	0	0
OTHER	4	0	0	0	6	0	0	0

Selection of appropriate restoration and rebuilding parameters presents a more complex problem because of the need to link these values to physical damage levels in the disaster. Industry functional restoration and rebuilding will generally proceed more slowly with increasing severity of the disaster and extent of physical damage. For this reason, it is recommended that to run a User-Supplied Data Analysis for Indirect Economic Loss that the user first run all of the preceding modules in **HAZUS**, examine the damage results, modify the restoration and rebuilding parameters as appropriate, and then finally run the Indirect Loss module. Several example restoration and rebuilding parameter sets designed based on expert opinion to represent different scales of disaster are presented below, together with a suggested algorithm for the user to select the most appropriate one.

The following suggested procedure attempts to provide a rough but simple and credible link between restoration and rebuilding parameters in the Indirect Loss module and **HAZUS** results on physical damage. Lifeline rebuilding and transportation industry functional restoration are linked to highway bridge damage. Manufacturing industry restoration is linked to industrial building damage. Buildings rebuilding and restoration for all other industries is linked to commercial building damage. The values of the industry functional restoration parameters are intended to reflect not only facility damage levels but also each industry's resiliency to damage to its facilities, such as for example its ability to relocate or utilize alternative facilities. These parameters were derived judgmentally with consideration of observations from previous disasters. Note that values for "restoration" in **HAZUS** represent the percent *loss of industry function* averaged over the year.

STEP 1. Calculate damage indices for highway bridges and commercial and industrial buildings, respectively. The damage index consists of the percent of structures in the "extensive" or "complete" damage states. For example, if results indicate that 5 percent of bridges will suffer "extensive" damage and 3 percent "complete" damage, the damage index is 8 percent. Damage results for bridges can be found in the **HAZUS** summary report on Transportation Highway Bridge Damage. Damage results for commercial and industrial buildings can be found in the **HAZUS** summary report on Building Damage by General Occupancy.

STEP 2. Select transportation industry restoration parameters and rebuilding parameters for lifelines. Use the highway bridge damage index from Step 1 to read off parameters from Table 16.15.

STEP 3. Select manufacturing industry restoration parameters. Use the industrial building damage index from Step 1 to read off parameters from Table 16.16.

STEP 4. Select restoration parameters for all other industries and rebuilding parameters for buildings. Use the commercial building damage index from Step 1 to read off parameters from Table 16.17.

Table 16.15 Transportation Restoration and Lifeline Rebuilding Parameters
(percentage points)

Highway bridge damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/ minimal	Restoration function - TRNS Ind.	0	0	0	0	0
		Rebuilding expenditures - Lifelines	100	0	0	0	0
0-1%	Minor	Restoration function - TRNS Ind.	2	0	0	0	0
		Rebuilding expenditures - Lifelines	100	0	0	0	0
1-5%	Moderate	Restoration function - TRNS Ind.	5	0	0	0	0
		Rebuilding expenditures - Lifelines	95	5	0	0	0
5-10%	Mod.-major	Restoration function - TRNS Ind.	10	2	0	0	0
		Rebuilding expenditures - Lifelines	90	10	0	0	0
10-20%	Major	Restoration function - TRNS Ind.	15	3	0	0	0
		Rebuilding expenditures - Lifelines	85	15	0	0	0
>20%	Catastrophic	Restoration function - TRNS Ind.	20	5	0	0	0
		Rebuilding expenditures - Lifelines	80	20	0	0	0

Table 16.16 Manufacturing Restoration Parameters
(percentage points)

Industrial building damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/minor	Restoration function - MFG Ind.	1	0	0	0	0
0-1%	Moderate	Restoration function - MFG Ind.	2	0	0	0	0
1-5%	Mod.-major	Restoration function - MFG Ind.	4	0	0	0	0
5-10%	Major	Restoration function - MFG Ind.	8	2	0	0	0
>10%	Catastrophic	Restoration function - MFG Ind.	20	10	5	0	0

Table 16.17 All Other Industries Restoration and Buildings Rebuilding Parameters
(percentage points)

Commercial bldg. damage index	Impact description	Parameter Set	Year 1	Year 2	Year 3	Year 4	Year 5
0%	None/minor	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	0	0	0	0	0
		Restoration function - TRDE Ind.	1	0	0	0	0
		Restoration function - FIRE Ind.	0	0	0	0	0
		Restoration function - SERV Ind.	1	0	0	0	0
		Restoration function - GOVT Ind.	1	0	0	0	0
		Restoration function - MISC Ind.	1	0	0	0	0
		Rebuilding expenditures - buildings	100	0	0	0	0
0-1%	Moderate	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	1	0	0	0	0
		Restoration function - TRDE Ind.	2	0	0	0	0
		Restoration function - FIRE Ind.	1	0	0	0	0
		Restoration function - SERV Ind.	2	0	0	0	0
		Restoration function - GOVT Ind.	2	0	0	0	0
		Restoration function - MISC Ind.	2	0	0	0	0
		Rebuilding expenditures - buildings	80	20	0	0	0
1-5%	Mod.-major	Restoration function - AG Ind.	0	0	0	0	0
		Restoration function - MINE Ind.	0	0	0	0	0
		Restoration function - CNST Ind.	2	0	0	0	0
		Restoration function - TRDE Ind.	4	0	0	0	0
		Restoration function - FIRE Ind.	2	0	0	0	0
		Restoration function - SERV Ind.	4	0	0	0	0
		Restoration function - GOVT Ind.	4	0	0	0	0
		Restoration function - MISC Ind.	4	0	0	0	0
		Rebuilding expenditures - buildings	70	30	0	0	0
5-10%	Major	Restoration function - AG Ind.	1	0	0	0	0
		Restoration function - MINE Ind.	1	0	0	0	0
		Restoration function - CNST Ind.	4	0	0	0	0
		Restoration function - TRDE Ind.	8	2	0	0	0
		Restoration function - FIRE Ind.	4	0	0	0	0
		Restoration function - SERV Ind.	8	2	0	0	0
		Restoration function - GOVT Ind.	8	2	0	0	0
		Restoration function - MISC Ind.	8	2	0	0	0
		Rebuilding expenditures - buildings	60	30	10	0	0
>10%	Catastrophic	Restoration function - AG Ind.	2	0	0	0	0
		Restoration function - MINE Ind.	2	0	0	0	0
		Restoration function - CNST Ind.	10	5	0	0	0
		Restoration function - TRDE Ind.	20	10	5	0	0
		Restoration function - FIRE Ind.	10	5	0	0	0
		Restoration function - SERV Ind.	20	10	5	0	0
		Restoration function - GOVT Ind.	20	10	5	0	0
		Restoration function - MISC Ind.	20	10	5	0	0
		Rebuilding expenditures - buildings	50	30	15	5	0

16.5.3 Advanced Data and Models Analysis

For this level of analysis, it is presumed that an economist with experience in the economics of natural hazards will be conducting the study.

16.5.3.1 Extending the Indirect Loss Module

The Indirect Loss Module above holds great potential for further development. Some of the alterations that could be incorporated are:

1. Expand the number of industries to better reflect building classes and individual lifelines.

2. Investigate the implications of how shortages and surpluses are addressed. The current Module follows a particular sequence for alleviating bottlenecks; it is possible that this sequence may influence the final results. As currently programmed, the algorithm attempts to resolve shortfalls by looking first to regional excess capacities. In some instances it may be more realistic to expect local producers to look to imports as a source of replacement. There is no obvious *a priori* way of knowing which alternative will be chosen. The particular sequence currently imbedded in the program will tend to maximize production at the local level and therefore minimize the indirect losses associated with an earthquake.

   A more appealing method would be to randomize the priority in which different avenues of ameliorating bottlenecks are chosen. Under this regime, the entire modeling process would be imbedded in a larger iterative loop that could explore a full range of options. By so doing, the robustness of the solution set can be assessed.

   Alternatively, survey research might be conducted which would ascertain how producers might actually respond to an earthquake. The model could then be modified to reflect this information.

3. Make parameter values sector specific. Currently, the methodology is designed so that the supply and demand options (imports, exports, capacity, and inventory adjustments) are identical across sectors. The next logical step would be to make these adjustments sector dependent. This would allow the analyst to better tailor the model to the circumstances of a particular location. For instance, if industry A required the output of industry B, and no substitutes or imports were permitted, a matrix of import probabilities would assign 0% at the intersection of these two industries.

   Additionally, such matrices would allow for consideration of instances where different industries have dissimilar responses to changes in the same input. If industry A requires a large amount of input C, while industry B requires a smaller amount, industry B would be more likely to pay a premium to import input C.

Although this notion seems daunting, it might be possible to incorporate the parameter matrix idea without making the modeling process totally infeasible. For example, one might begin by assigning a scalar, say 10%, to the entire matrix of import probabilities. Then, entire industries could be modified by inputting vectors of new values to those industries. Finally, key intersections for the local economy could be located and specific parameters applied to those intersections. Therefore, at its simplest level, the parameter matrix concept is no more complex than what is currently programmed into the Indirect Loss Module.

4. Approximate price effects. A common complaint leveled against I/O models is that they do not incorporate prices. While this is true, a couple of points need to be made in reference to this particular Loss Module. Significant relative price changes have not been observed after disaster. This may be due in part to special circumstances emerging during the post-disaster period, where price “gouging" is frowned upon, or made illegal (as in Los Angeles after the Northridge earthquake).

However, if concerns about price effects remain, it should be possible to modify the Module accordingly. As the system is currently configured, there are fixed constraints on output, imports, etc. In a supply and demand framework, these could be thought of as a series of discontinuous supply curves which are horizontal until the quantity constraint is reached, at which point they turn perfectly vertical. Enhancement of this system with a function that reduces output as new input sources are tapped would mimic a price-sensitive supply function. However, it must be pointed out that parameterization of such functions is an extremely difficult task. This is one of the problems that Computable General Equilibrium models also face.

5. Extend the model to asses indirect loss/gain incurred by surrounding regions and the national economy. As it now stands, the model is best suited to analysis of the immediately impacted region. However, as pointed out early in the Chapter, regional consequences may be quite different than that measured at the national level. Figure 16.19 indicates how the module could be extended to account for these broader economic linkages. Direct damages and subsequent indirect loss is transmitted to other regions via changes in the import-export relationships. The national economy is impacted in that external aid has to be financed, either at the expense of canceled federal projects, or increased tax liability. In either case demands elsewhere will suffer.

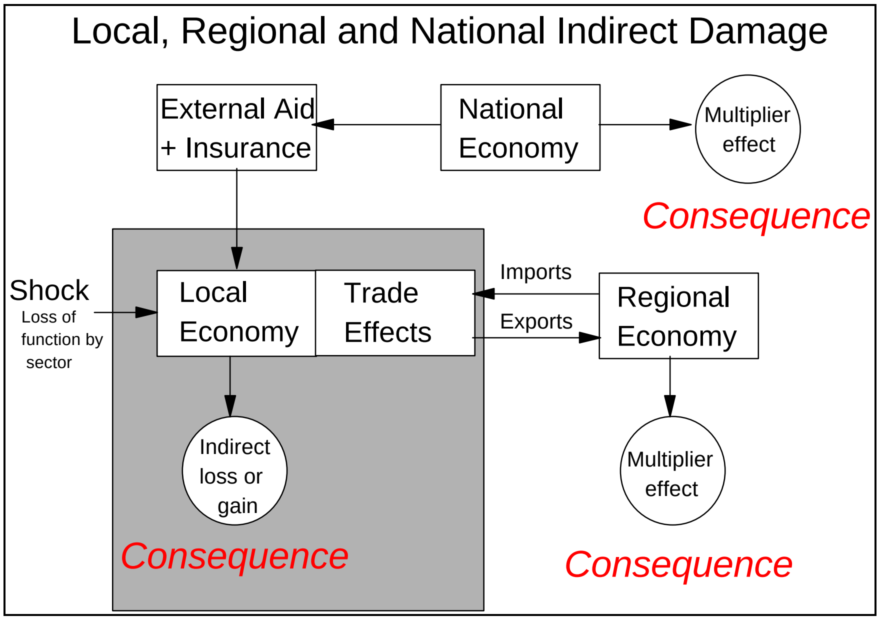


Figure 16.6 Extending the Model to Include Larger Regional and National Losses

16.5.3.2 Alternative Modeling Techniques

It is possible for an economist to use other modeling strategies in conjunction with this loss estimation methodology. For instance, if the region being studied already utilizes a working Computable General Equilibrium model, it could be used to estimate indirect economic loss. Linear Programming methods are also potentially useful. Finally, though not recommended, it is possible to simply feed the direct loss information through a standard set of I-O multipliers (see the discussions in Sections 16.2 and 16.3 above).[10]

---

[10] See, for example, Shoven and Whaley (1992) for general discussion of CGE systems, and Brookshire and McKee (1992) and Boisvert (1995) for applications to earthquakes.

Linear programming offers a simpler alternative to the CGE approach (Cochrane, 1975; Rose et al., 1997). Again, interindustry trade flows form the basis of the model. As in the previous two methods, the A matrix guides the reallocation of production; the output of each sector is comprised of a fixed proportion of other sector outputs. However, unlike the previous methods, an optimizing routine is utilized to search for that production combination that minimizes the extent to which regional income is impacted by the event.

The results derived from I-O, LP and CGE models are likely to vary. Linear programming is likely to provide the most optimistic projection of loss and the Indirect Loss Module the most pessimistic. The reason for this conclusion rests on the high degree of flexibility assumed (in both the CGE and linear programming) in shifting resource use. It is unlikely that production could be redirected without concern for contractual arrangements, or without considering household preferences. The optimization alternative typically ignores both, though this problem can be mitigated somewhat by the inclusion of explicit constraints (see, for example, Rose and Benavides, 1997).

16.6 Example Solutions

The following examples are provided to both illustrate how a typical indirect loss analysis is performed, and to show the wide range of results possible. Indirect loss patterns (produced from thousands of monte carlo simulations) are then analyzed to derive several general principles relating direct and indirect losses. The resultant patterns and assessments are provided to assist the user in interpreting their own results. First, a simple one-sector supply shock is analyzed to clarify how the model works. The Colorado State Hazards Assessment Laboratory version of the Indirect Loss Module was utilized to perform these analyses. This was done in order to isolate and analyze particular damage patterns. This will create slight discrepancies between **HAZUS** model output and what is reported by the CSU model.

16.6.1 Simple One-Sector Supply Shock - No Excess Capacity

Table 16.20 shows the final solution for the example discussed above in Section 16.5.1.2, i.e., a 30 percent decline in the functionality of the transportation sector. In this experiment no adjustments were permitted (all percentages are zero except for the supply shock). Table 16.19 shows the initial conditions (output, income and employment) and the adjusted capacities. The mobility of the construction industry shows up as excess capacity. Because reconstruction spending in the example is assumed zero, the capacity goes unutilized. Table 16.20 (right hand side) shows the resultant impact on output, income and employment. The overall percent reduction in these three categories is computed from regional outputs, incomes and employments with and without the event.

In this example of a highly constrained economy, the 30 percent shock to transportation, produces 1.07, 1.46, and a 1.06 percent change in *direct* output, income and employment, respectively. Because of the constraints assumed, total losses (direct and indirect) are approximately 30 times the direct loss (nearly 30 percent).

16.6.2 The Northridge Earthquake

The following scenarios illustrate the sensitivity of indirect loss to the amounts of outside assistance provided and the degree to which the lifelines (particularly transportation) are disrupted. Four scenarios are presented along with the inputs required to run the Indirect Loss Module. Scenario A looks at the twin effects of $26 billion of reconstruction spending, financed internally (i.e., no external aid), and temporary disruption to the transportation system. Scenario B removes reconstruction spending. Scenario C removes the transportation constraint, but eliminates rebuilding. Scenario D removes the transportation constraint, while the $26 billion of rebuilding expenditures is assumed to be financed by a combination of insurance moneys and federal aid.

Table 16.21 shows the IMPLAN transactions matrix for Los Angeles county. Tables 16.23 and 16.24 summarize the inputs used. The results provided in Tables 16.22, 16.25, 16.27 and 16.31 point out several important issues. First, Scenario D comes closest to capturing what did occur. A relatively small proportion of the rebuilding costs were financed internally. As a result, the negative effects of the disruption to transportation were masked by the stimulative effect of rebuilding. The 7.83% net increase in incomes earned in the county are surprisingly close to the observed rise in Los Angeles County taxable sales (7.35%).

Table 16.18 Initial Transactions Matrix

Initial Shock	**0.00**	**0.00**	**0.00**	**0.00**	**30.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**Total**
Total Change	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**Change**
	Ag	**Mine**	**Cnst**	**Mfg**	**Trns**	**Trde**	**FIRE**	**Serv**	**Govt**	**Misc**	**HH**	
Ag	730	0.1	24.6	503.8	2.3	35.1	141.1	34	1.9	0	145.5	0.00%
Mine	1.1	11.6	6.1	12.7	4.2	0.8	0.2	1.6	2.1	0	20.7	0.00%
Cnst	87.5	6	13.8	295.4	248.4	48.1	403.8	313.4	172.6	0	0	0.00%
Mfg	71.6	8.4	384.6	4,791	51.9	178.8	37.3	424.1	7.8	0	1,565	0.00%
Trns	218.3	20.4	261.2	1,468.2	456.7	200.1	126.7	361.3	76.2	0	1,624	0.00%
Trde	99.8	4.1	461.8	994.1	44.2	78.7	27.2	214	12.8	0	8,477	0.00%
FIRE	195.3	24.5	85.4	279.4	91.5	228.4	1,132	702.1	13	0	10,005	0.00%
Serv	93.4	12.7	552.5	789.5	171.3	294.6	300.6	1,032.1	19.3	0	10,147	0.00%
Govt	28.6	6	22.8	313.5	36.8	78.3	71.3	169.7	29	0	582	0.00%
Misc	0	0	0	0	0	0	0	0	0	0	0	0.00%
HH	1,879	195	3,704	12,729	2,266.3	7,305	2,108	9,724	6,567	0	0	0.00%
											Sum	0.00%

Table 16.19 Original Conditions and Adjustments

	Original Conditions			Additional Demands			Additional Supplies		
Sector	Output	HH Payments	Employ.	Inventory Buildup Capability	Export Capability	Desired New Final Demand	Potential Output Increase	Potential Imports	Potential Inventory Drawdown
Ag	5,964	1,879	106,253	0	0	0	0	0	0
Mine	1,092	195	4,739	0	0	0	0	0	0
Cnst	10,984	3,704	144,407	0	0	0	10,040	0	0
Mfg	52,811	12,729	378,400	0	0	0	0	0	0
Trns	7,169	2,266	72,169	0	0	0	0	0	0
Trde	13,484	7,306	451,276	0	0	0	0	0	0
FIRE	15,791	2,108	124,514	0	0	0	0	0	0
Serv	19,065	9,724	492,969	0	0	0	0	0	0
Govt	7,550	6,567	266,107	0	0	0	0	0	0
Misc	0	0	0	0	0	0	0	0	0
HH									
Totals	66,312	46,478	2,040,834						

Table 16.20 Final Conditions

		Post- Event Spending					Final Losses		
Sector	Net Change Next Round	Hhld Spending	Exports	Post-Event Final Output	Final Output Direct Loss Only	Post-Event Hhld Payments	Hhld Payments Direct Loss Only	Post-Event Employ.	Employ. Direct Loss Only
Ag	29.98%	102	1,284	4,176	5,964	1,316	1,879	74,398	106,253
Mine	29.98%	15	285	765	1,092	137	195	3,318	4,739
Cnst	29.98%	0	252	7,691	10,984	2,594	3,704	101,113	144,407
Mfg	29.98%	1,096	12,565	36,978	52,811	8,914	12,729	264,955	378,400
Trns	30.00%	1,137	617	5,018	5,018	1,586	1,586	50,518	50,518
Trde	29.98%	5,936	801	9,442	13,484	5,116	7,306	315,982	451,276
FIRE	29.98%	7,005	865	11,057	15,791	1,476	2,108	87,184	124,514
Serv	29.98%	7,105	1,608	13,349	19,065	6,809	9,724	345,175	492,969
Govt	29.98%	408	97	5,287	7,550	4,599	6,567	186,327	266,107
Misc	0.00%	0	0	0	0	0	0	0	0
HH									
Totals		22,802	18,375	140,194	198,072	32,544	45,798	1,428,970	2,019,183
Total % Change	29.98%	-29.98%	-29.98%	-29.98%	-1.07%	-29.98%	-1.46%	-29.98%	-1.06%

Second, the effects of transportation bottlenecks alone can only be observed by stripping away rebuilding expenditures, Scenario B. Here we can see that income would have fallen, not risen. The disaster would have caused another $10 billion in indirect losses. Third, outside assistance is an important element in the recovery process. The effects of internal financing are shown in

Scenario A. Here, an additional $1.5 billion in income losses would have been observed had the victims been forced to borrow to rebuild.

These scenarios underscore the importance of rebuilding on the impacted region's post-disaster economic performance. This is particularly true when insurance and federal assistance is made available. Another important lesson learned from these experiments is that case studies of indirect loss can produce misleading results. Clearly Northridge and Los Angeles County did not benefit from disruptions to its transportation network. Yet, an analysis of post-disaster spending and incomes (taxable sales reported after the earthquake) tends to indicate such had occurred. As just shown the Indirect Loss Module is capable of separating the stimulative effects of rebuilding from the "true" indirect losses produced as a result of forward and backward linked damages.

Table 16.21 Los Angeles County Transactions Matrix

	Ag	Mine	Cnst	Mfg	Trns	Trde	FIRE	Serv	Govt	Misc	HH
Ag	26	0	28	173	2	13	213	46	5	0	49
Mine	2	1	13	66	44	16	2	22	53	0	119
Cnst	14	10	24	353	482	167	1162	694	603	0	0
Mfg	121	25	1942	13201	1363	1707	378	3415	285	0	12219
Trns	50	38	929	4069	2381	1724	920	2741	1078	0	6677
Trde	43	6	1609	2662	207	511	140	904	103	0	21900
FIRE	60	189	301	1080	653	1519	7279	4210	134	0	28696
Serv	122	37	2839	4933	1916	4636	3177	14326	275	0	31357
Govt	17	25	96	1195	200	651	389	1213	255	0	2514
Misc	0	0	0	0	0	0	0	0	0	0	0
HH	660	424	8846	30473	8601	25129	10985	51410	17318	0	0
TypeII sum	1115	754	16627	58204	15850	36072	24645	78981	20111	0	103530
TypeII FP	431	4936	7708	62601	10039	13605	32460	13019	1838	0	57838
Imports	403	1201	6920	42925	3400	3284	1744	6543	669	0	0
Ind Out	1546	5690	24335	120805	25888	49677	57105	92000	21948	0	161368

Table 16.22 Results – Scenario A
Constrained Transportation Sector
Reconstruction

Direct Output Loss	($15,508)	-2.77%
Indirect Output Loss	$8,286	1.48%
Total Loss (Direct+Indirect)	($7,222)	-1.29%
Direct Income Loss	($3,710)	-2.41%
Indirect Income Loss	$1,552	1.01%
Total Loss Income (Direct+Indirect)	($2,158)	-1.40%
Direct Employment Loss	(122,015)	-2.39%
Indirect Employment Loss	24,013	0.47%
Total Employment Loss (Direct+Indirect)	(98,002)	-1.92%

Table 16.23 Scenario A; Damage and User Inputs

Economic Sector	Percent Damage
Agriculture	0.00%
Mining	0.00%
Construction	0.00%
Manufacturing	3.80%
Transportation	10.00%
Trade	3.50%
Finance, Insurance and Real Estate	2.00%
Service	0.86%
Government	0.87%
Misc.	0.00%

Assumptions	Value
Rate of Unemployment	8.00%
Excess Capacity in Transportation	0.00%
Earthquake Construction Spending	$26 billion

Table 16.24 Restoration and Reconstruction Spending after Northridge

SECTOR	Months after the Northridge Earthquake										
	1	2	3	6	9	12	24	36	48	60	120
Agriculture	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mining	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Construction	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Manufacturing	3.80	3.19	2.58	1.98	1.37	0.76	0.15	0.00	0.00	0.00	0.00
Transportation	10.00	8.40	6.80	5.20	3.60	2.00	0.40	0.00	0.00	0.00	0.00
Trade	3.50	2.94	2.38	1.82	1.26	0.70	0.14	0.00	0.00	0.00	0.00
FIRE	2.00	1.68	1.36	1.04	0.72	0.40	0.08	0.00	0.00	0.00	0.00
Service	0.86	0.72	0.58	0.45	0.31	0.17	0.03	0.00	0.00	0.00	0.00
Government	0.87	0.73	0.59	0.45	0.31	0.17	0.03	0.00	0.00	0.00	0.00
Misc.	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Spending/Mn	Months after the Northridge Earthquake										
	1	2	3	6	9	12	24	36	48	60	120
$ Billons	0.10	0.30	0.60	0.70	0.70	0.60	0.30	0.12	0.00	0.00	0.00

Table 16.25 Results – Scenario B
Constrained Transportation Sector
No Reconstruction

Direct Output Loss	($15,508)	-2.77%
Indirect Output Loss	($33,685)	-6.01%
Total Loss (Direct+Indirect)	($49,193)	-8.78%
Direct Income Loss	($3,710)	-2.41%
Indirect Income Loss	($9,692)	-6.30%
Total Loss Income (Direct+Indirect)	($13,403)	-8.71%
Direct Employment Loss	(122,015)	-2.39%
Indirect Employment Loss	(318,930)	-6.24%
Total Employment Loss (Direct+Indirect)	(440,945)	-8.63%

Table 16.26 Scenario B, User Inputs

Assumptions	Value
Rate of Unemployment	8.0%
Excess Capacity in Transportation	0.00%
Earthquake Construction Spending	$0 billion

Table 16.27 Results – Scenario C
Unconstrained Transportation Sector
No Reconstruction

Direct Output Loss	($15,508)	-2.77%
Indirect Output Loss	$2,648	0.47%
Total Loss (Direct+Indirect)	($12,860)	-2.29%
Direct Income Loss	($3,710)	-2.41%
Indirect Income Loss	$640	0.42%
Total Loss Income (Direct+Indirect)	($3,070)	-2.00%
Direct Employment Loss	(122,015)	-2.39%
Indirect Employment Loss	21,250	0.42%
Total Employment Loss (Direct+Indirect)	(100,765)	-1.97%

Table 16.28 Scenario C, User Inputs

Assumptions	Value
Rate of Unemployment	8.00%
Excess Capacity in Transportation	no constraint
Earthquake Construction Spending	$0 billion

Table 16.29 Results – Scenario D
Unconstrained Transportation Sector
Reconstruction, No Indebtedness

Direct Output Loss	($9,754)	-2.12%
Indirect Output Loss	$37,061	8.05%
Total Loss (Direct+Indirect)	$27,307	5.93%
Direct Income Loss	($2,850)	-1.85%
Indirect Income Loss	$12,046	7.83%
Total Loss Income (Direct+Indirect)	$9,196	5.98%
Direct Employment Loss	(99,044)	-1.94%
Indirect Employment Loss	370,072	7.24%
Total Employment Loss (Direct+Indirect)	271,028	5.31%

Table 16.30 Scenario D, User Inputs

Assumptions	Value
Rate of Unemployment	8.00%
Excess Capacity in Transportation	no constraint
Earthquake Construction Spending	$26 billion

16.6.3 The Sensitivity of Indirect Loss to Capacity, Damage and Reconstruction

Our analysis to date suggests that there may not be a simple relationship between direct and indirect losses. Much depends upon the pattern of damage, which sectors sustain the greatest disruption, and their relative importance in the economy. In addition, the demand stimulus inherent in the rebuilding process would lessen indirect loss, possibly producing gains in instances where large amounts of excess capacity exist. The sensitivity of indirect loss to random patterns of damage and rebuilding was determined through a series of experiments that are presented in summary form below. Four major classes of experiments were conducted; they are identified and explained in Table 16.31.

Table 16.31 Monte Carlo Experiments

Experiment	Explanation
Damage Pattern	1. Random damage pattern drawn from a uniform probability distribution (all sectors). 2. Random damage pattern drawn from a skewed probability distribution (all sectors). 3. Random pattern of damage to the lifelines sector, no damage to all other sectors.
Outside Assistance	4. Random amounts of rebuilding. 5. Rebuilding in proportion to direct losses
Economic Structure	Different transactions matrices were utilized to evaluate the extent to which economic structure impacted indirect loss when the economy was fully constrained
Internal and External Capacity	The effects of eliminating supplemental imports and exports and varying internal capacity.

Indirect and direct losses were recorded for twenty thousand experiments[11]. The joint density function of direct and indirect loss, along with the probability density function of indirect loss were then plotted to derive relationships capable of being generalized. See Figure 16.7. The joint density function is displayed on the higher of the two horizontal plains. Regions of indirect gain and loss are identified. The lower of the two planes is a contour map (projection) of the joint probability of indirect and direct loss. The back projection is the indirect loss probability density function.

The results of the experiments are plotted in Figures 16.8 through 16.17. As shown, either regional indirect loss or gain can be observed. Which occurs depends upon the combination of the damage pattern, preexisting economic conditions and the amount of outside assistance received. Several of the maps have ready explanations. The map shown in Figure 16.8 is based on two assumptions: 1) the existence of sufficient (to avoid shortages) excess capacity and 2) rebuilding expenditures are proportionate to direct loss. The first assumption eliminates all constraints and, therefore, indirect losses are eliminated as well. By linking reconstruction spending to direct loss, indirect gain (the effect of the construction multiplier) is made proportionate to direct loss. It will be shown below that the slope implied by the contour is a function of the construction multiplier.

It appears from these experiments that reconstruction spending exerts a powerful influence on indirect loss. Figure 16.9 shows the results of an experiment where internal capacity was varied randomly from zero to 30 percent, the shocks were drawn randomly from a uniform probability distribution, and reconstruction spending was random. As shown, indirect losses were recorded for fewer than 10 percent of the cases. Figure 16.10

[6]Damage to each of 10 economic sectors was determined by generating a random number between zero and one for the uniform distribution and cubing the random number to arrive at a skewed distribution.

shows the effect of eliminating reconstruction expenditures. As expected, the gains shown in Figure 16.8 disappear.

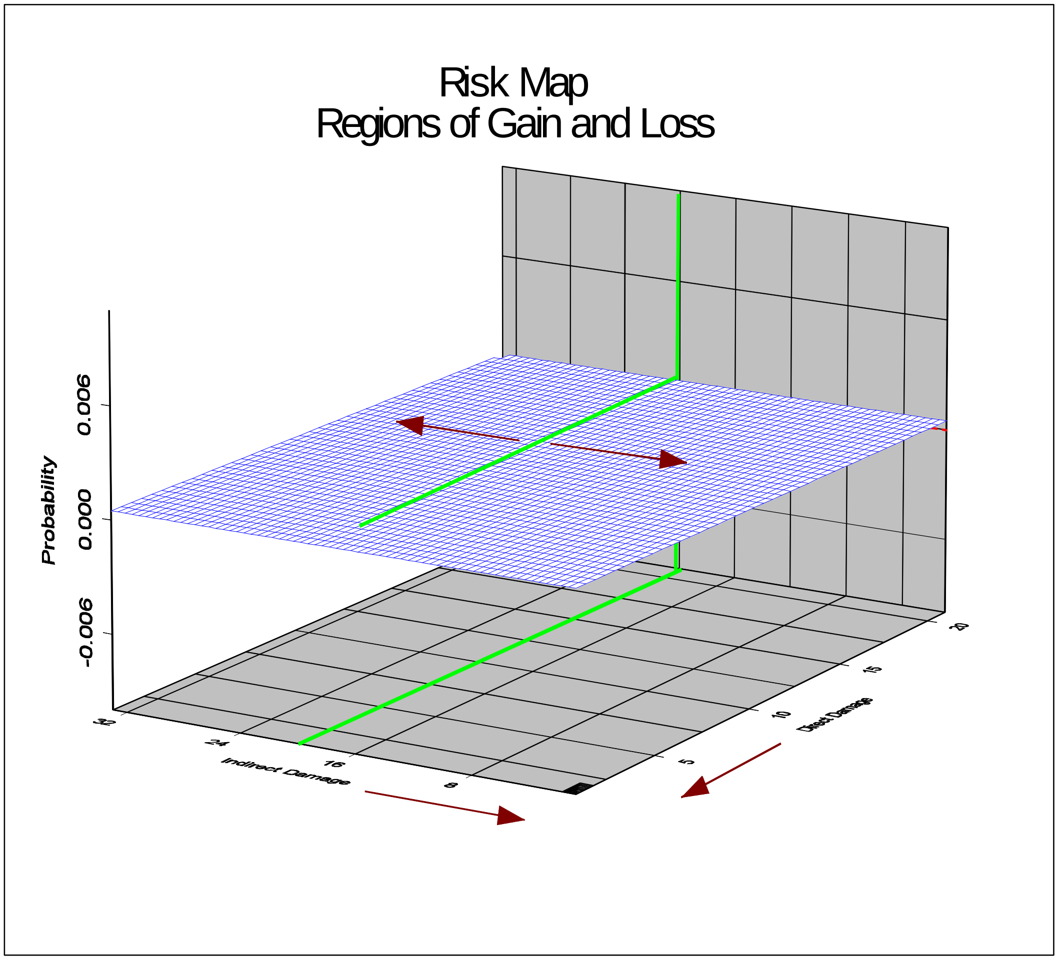


Figure 16.7 Risk Map - Direct vs. Indirect

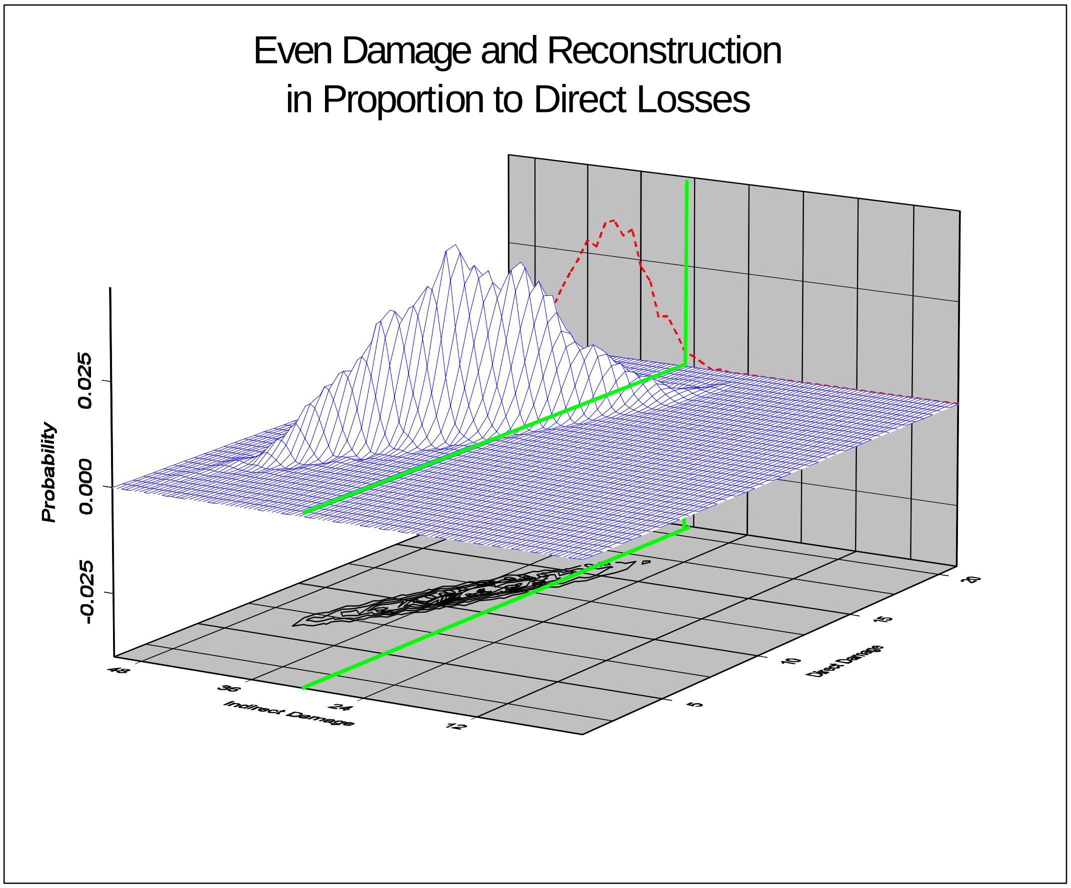


Figure 16.8 Risk Map - No Constraints

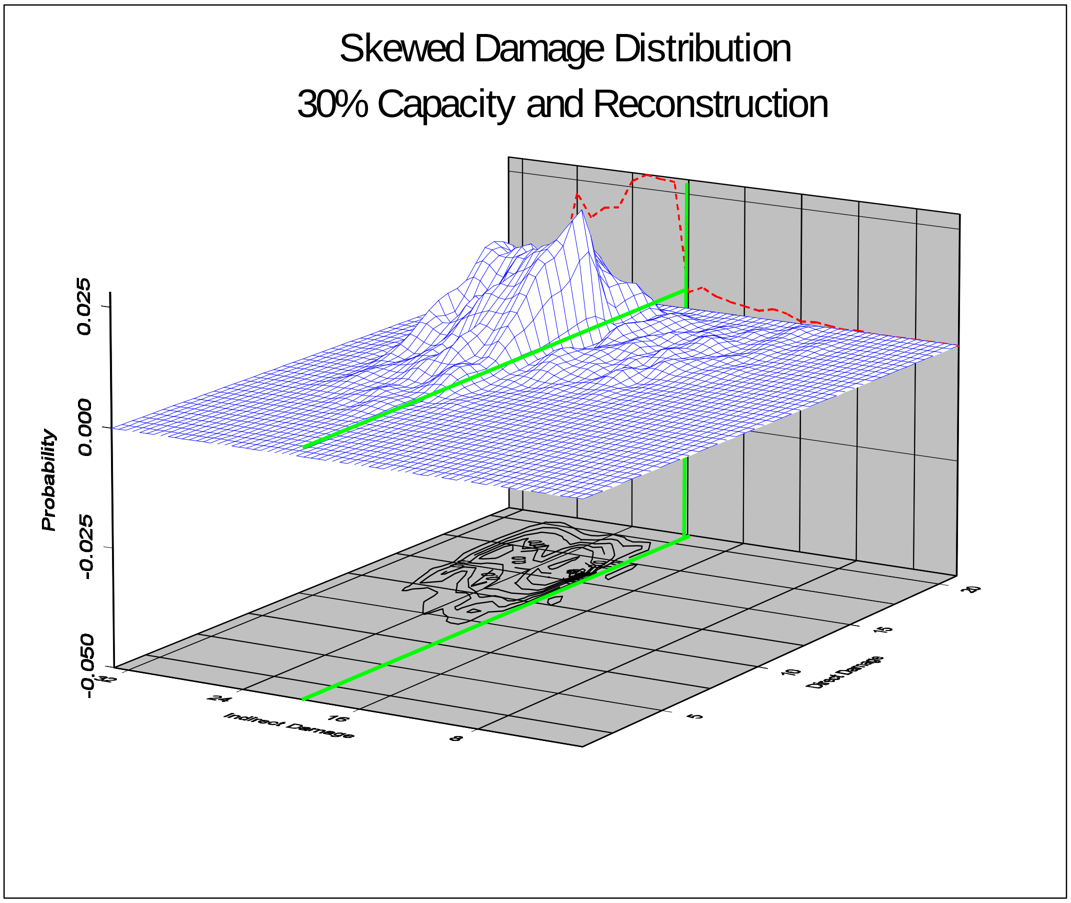


Figure 16.9 Risk Map - Random Capacity

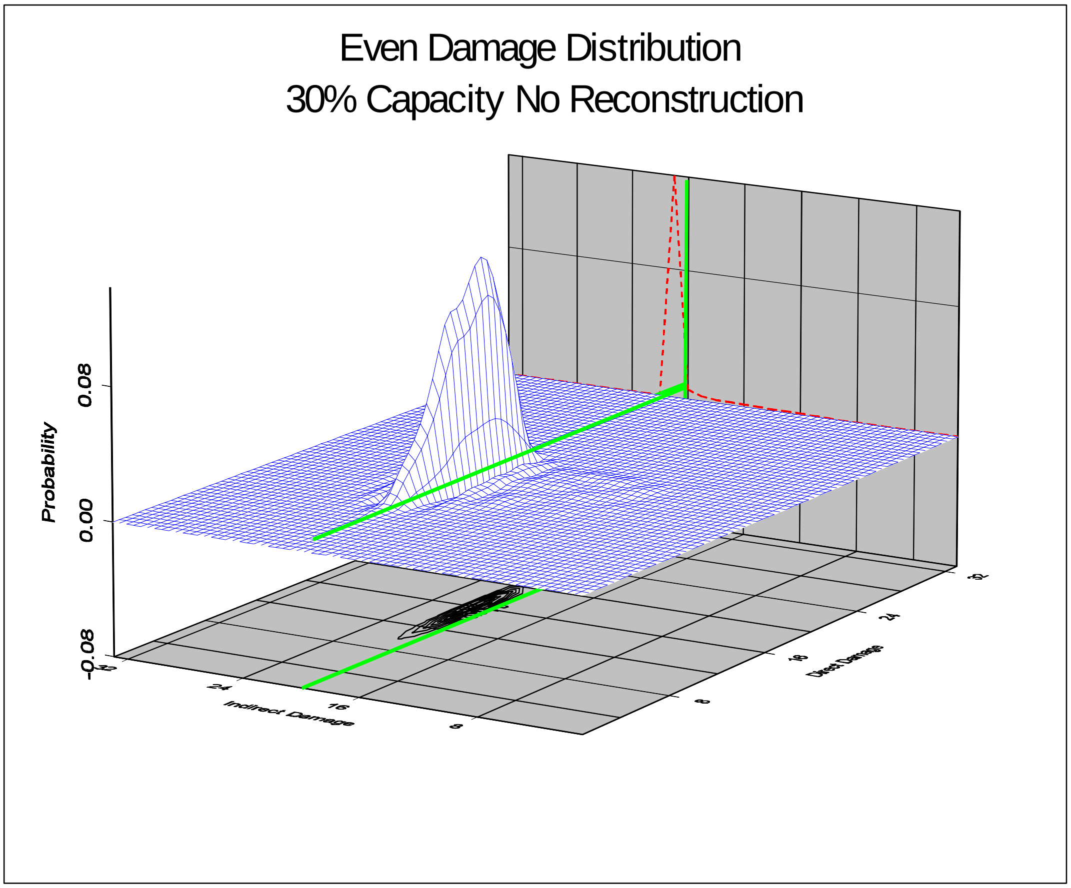


Figure 16.10 Risk Map - No Rebuilding In contrast, Figure 16.11 shows that when the economy is constrained (internally and externally) indirect losses can be quite high and indirect gains are impossible. The shape of this result map can be explained. The outline of the contour map provided in Figure 16.11 and several regions of the solution set are identified in Figure 16.12. The triangular shape of the map follows directly from the way in which the economy responds to damages. Point B, the uppermost level of indirect loss, results from a maximum shock to the smallest sector. Even though B proved to be improbable, other combinations of low direct loss and relatively high indirect loss were observed. The Line segment D-C shows the effect of a uniform[12] damage patterns. An even pattern of damages produce no indirect loss since the economy remains balanced. Only an uneven pattern of damage produces bottleneck effects and indirect losses. The line segment A-C can be interpreted as the indirect loss frontier. At the extreme, when direct loss is total, indirect loss must be zero. Similarly, when direct loss is total for the smallest sector, indirect loss is maximum. Hence, point A would be observed if the size of the smallest sector approached zero. Line segment D-B shows the

[12]Uniform means that each sector suffers an equal ratio of damage.

influence of increased variance in the pattern of loss. The variance is zero at D and maximum at B.

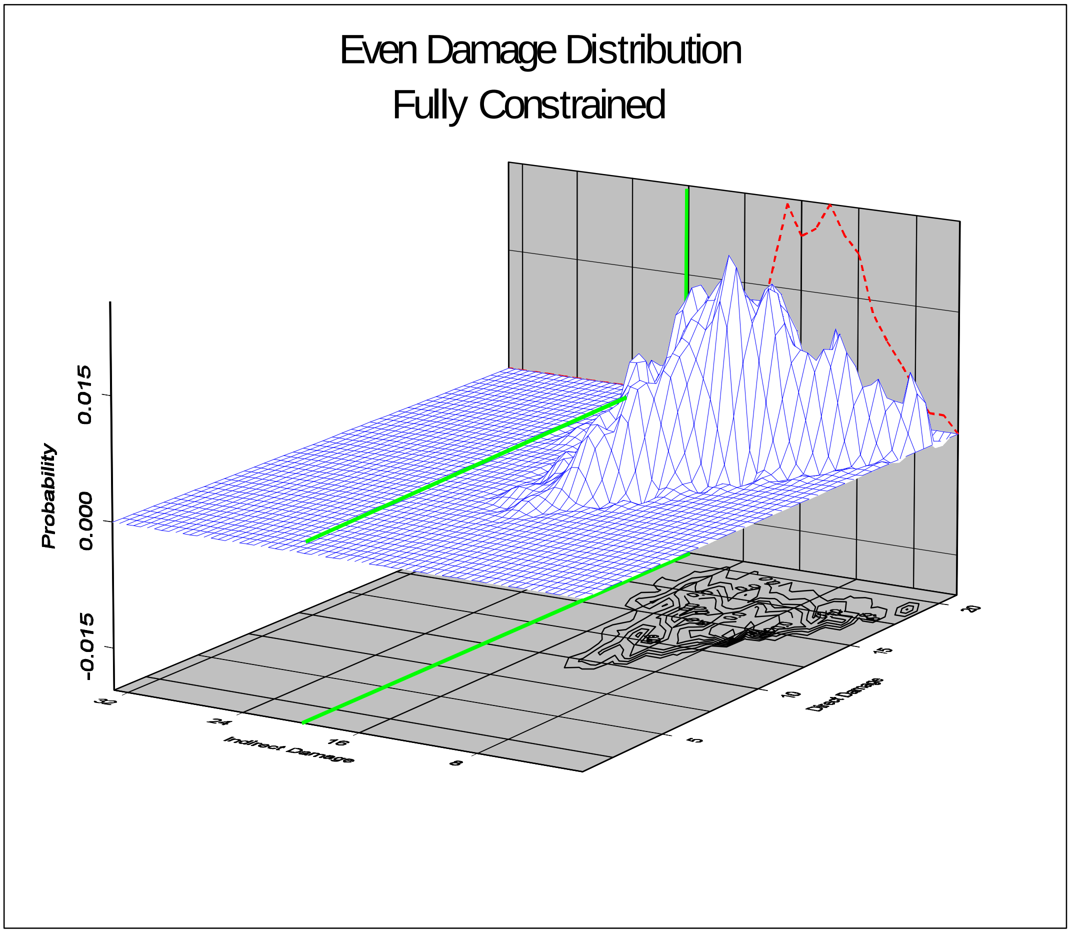


Figure 16.11 Risk Map Fully Constrained

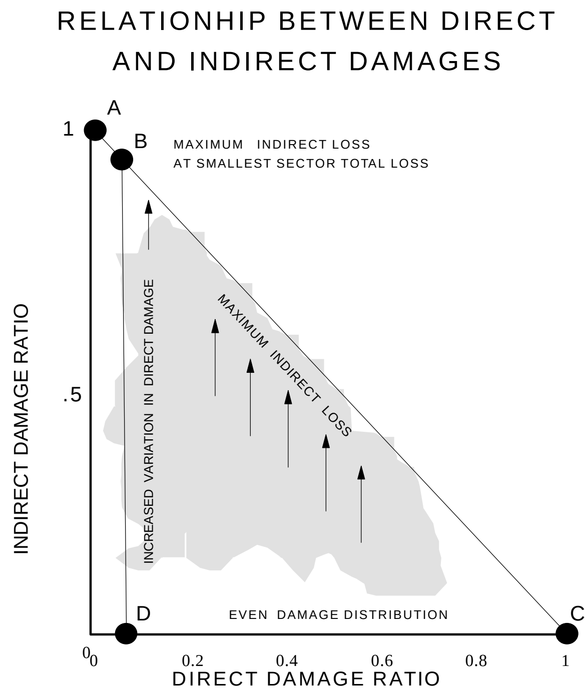


Figure 16.12 Relationship Between Direct and Indirect Damages

Figures 16.13 and 16.14 show the effect of a shock to lifelines (transportation) alone. The only difference between the two experiments is the amount of excess capacity assumed, 30 percent in the former and none in the latter. It is not surprising that this latter scenario produces the potential for sizable indirect losses.

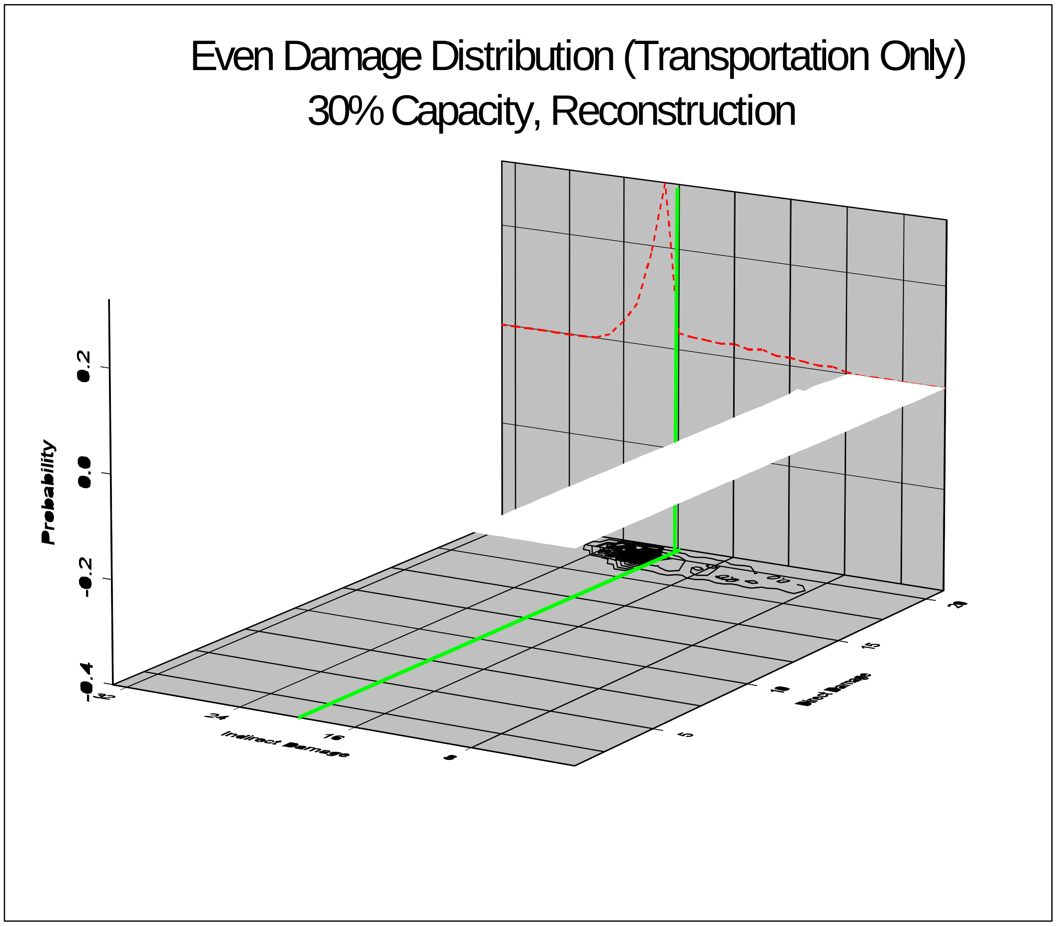


Figure 16.13 Risk Map - Transportation Disruption and Excess Capacity

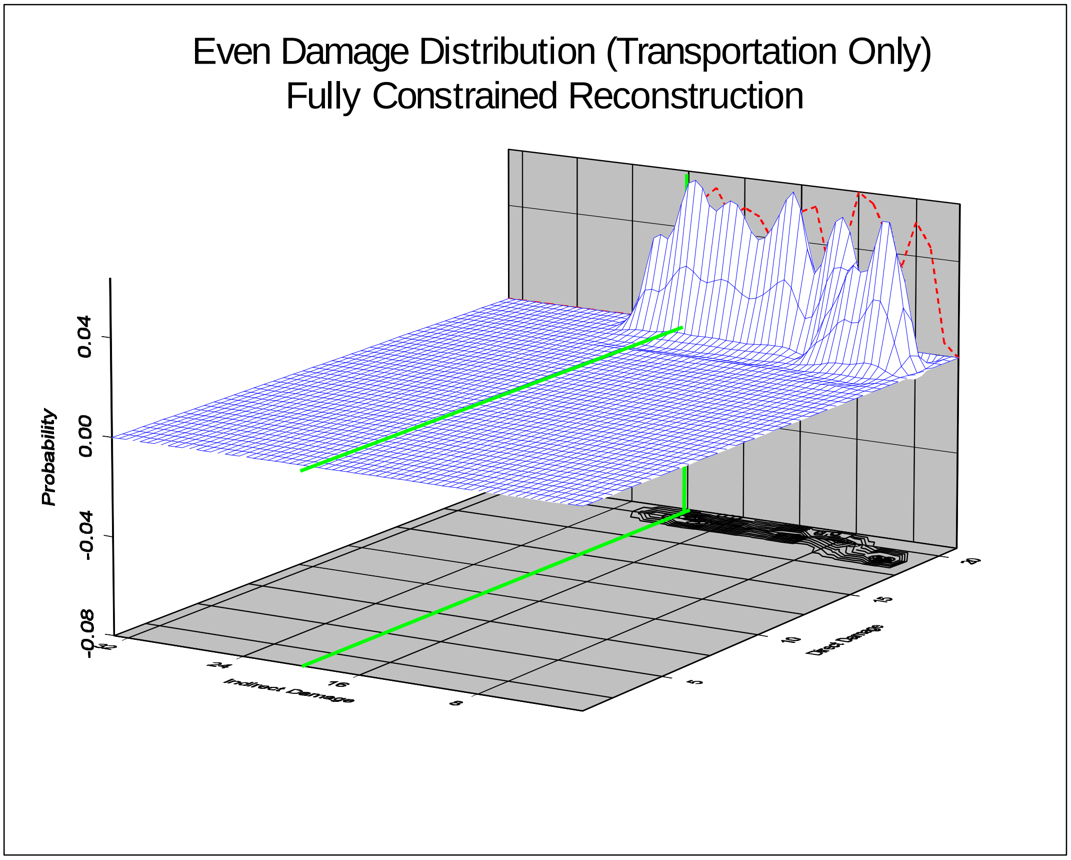


Figure 16.14 Risk Map - Transportation Disruption and No Excess Capacity

Figures 16.15, 16.16 and 16.17 provide a comparison of how economies respond to differing damage patterns, capacities and economic structure. Figure 16.15 summarizes the experiments that varied capacity. Figure 16.16 contrasts the degree of skewness in sectoral damage. As shown, the greater the concentration of damage, the greater the indirect loss as a proportion of total loss. The greater the capacity the greater the chances of indirect gain. Rebuilding expenditures enhances such gains. It is somewhat surprising in Figure 16.17 that economic structure appears to play an insignificant role in determining indirect losses when the economy is fully constrained. All three economies shown appear to produce very similar joint density functions. Clearly, the same conclusion will not apply in the event that internal excess capacity exists. In that case, economic gains are sensitive to economic structure, through a construction multiplier.

It was asserted above that, if unconstrained, this model produces a solution that is equivalent to what conventional input-output techniques yield. This is easily demonstrated by making reconstruction expenditures proportionate to direct loss. A simple linear regression of spending and indirect gain should produce a slope (zero intercept) equal to the construction multiplier. Figure 16.18 shows the result of this experiment. The slopes of the indirect gain functions for Los Angeles and Santa Cruz are

1.397 and 1.145 respectively. The respective IMPLAN construction multipliers for these two counties are 1.431 and 1.141.

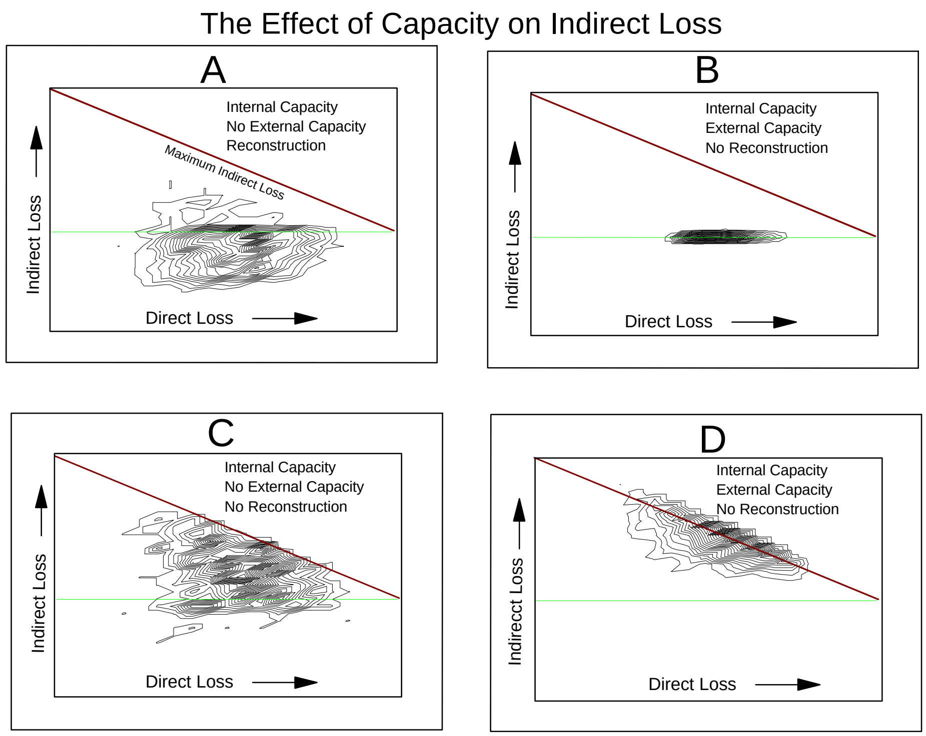


Figure 16.15 Risk Maps—The Effects of Capacity

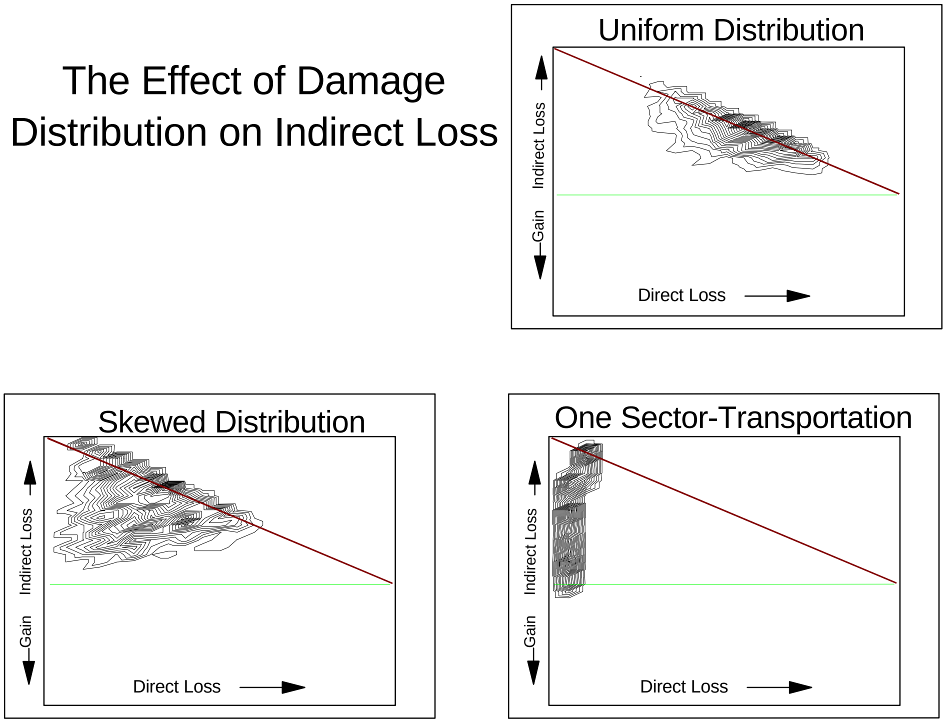


Figure 16.16 Risk Maps – The Effects of Damage Distributions

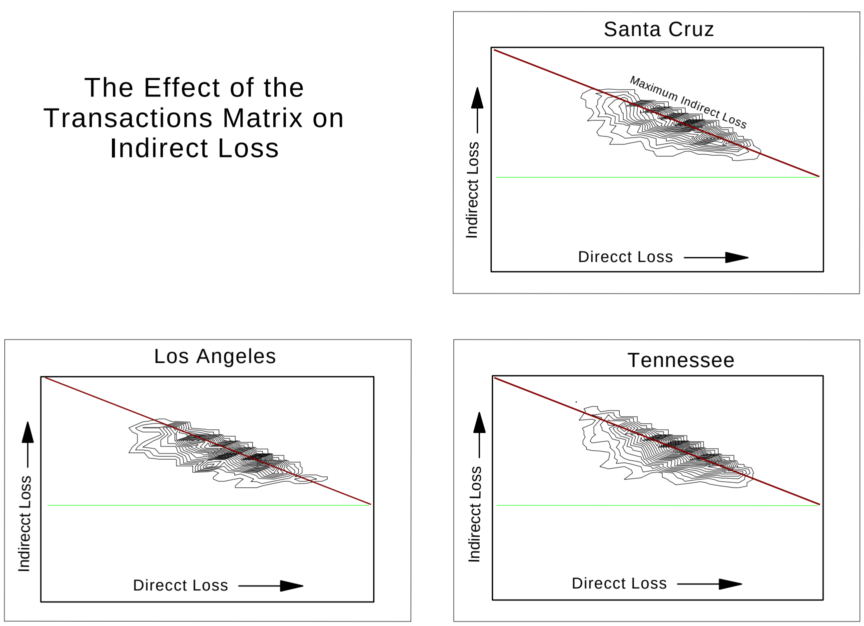


Figure 16.17 Risk Map -- The Effect of the Transactions Matrix When Fully Constrained

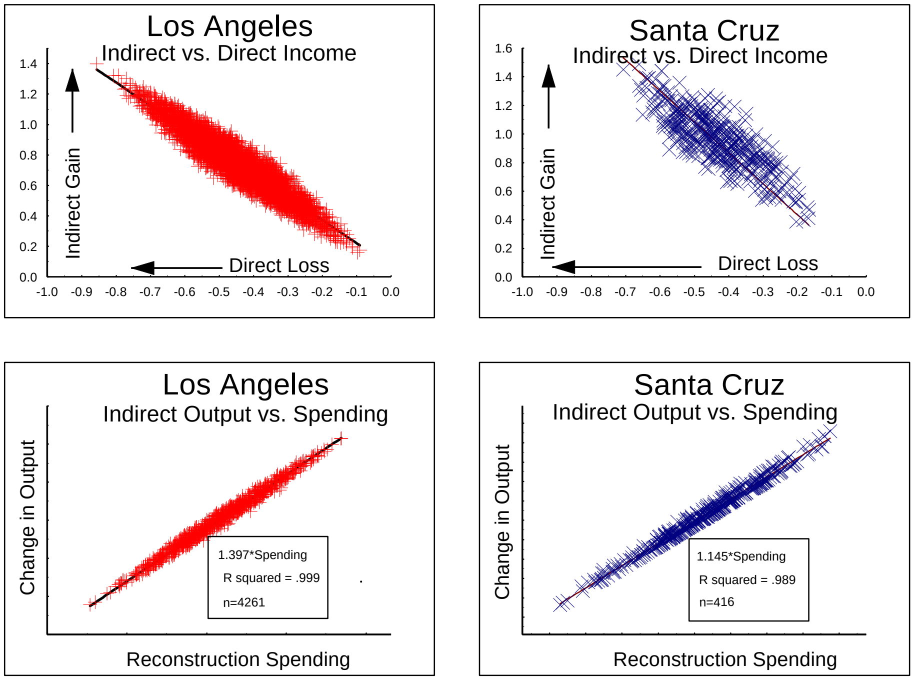


Figure 16.18 Indirect Gains and the Construction Multiplier

16.6.4 Observations About Indirect Loss

The following generalizations can be drawn from the foregoing experiments:

1. Holding capacity and rebuilding fixed, indirect losses are inversely proportional to the size of the sector shocked. For example, in the extreme case of an economy with a dominant sector, the rest of the economy in which indirect effects take place is relatively small.

2. Imports can either reduce or promote indirect loss, dampening losses if used to supply industry with raw and semi-finished ingredients so that production can be resumed, and accentuating losses if imports are used to satisfy unmet household demand, thus displacing local production.

3. Shocks to a fully constrained economy produce indirect losses, but not indirect gains because there is no leeway for the latter (e.g., multiplier effects from construction). In such an economy, the probability of indirect losses exceeding direct damage is approximately 50 percent.

4. The greater the variance in the pattern of damage, the greater the indirect loss due to factors such as “bottleneck” effects.

5. A uniform pattern of loss produces no indirect loss because internal rearrangements of buyers and sellers can be perfectly matched (barring transportation problems and contractual constraints).

6. If the economy is fully constrained, indirect losses are maximum when the economy's smallest sector is totally destroyed (this is the inverse of generalization No. 1).

7. When unconstrained, the economy expands from the construction stimulus as conventional I-O techniques (multipliers) would predict.

8. A dynamic analysis of indirect loss reflects both the forward and backward linked losses and future demand changes resulting from disaster caused indebtedness, both of which are generally long-run dampening effects.

9. When economies are fully constrained, indirect loss appears to be insensitive to economic structure. Different transactions matrices yield marginally different indirect losses, most likely because of similarities of multiplier values or stochastic offsets of multipliers of differing values.

10. From a regional accounting stance reconstruction gains tend to dominate indirect losses when excess capacity exists.

16.7 References

Alesch, D.J., C. Taylor, A. S. Ghanty, and R. A. Nagy, 1993, "Earthquake Risk Reduction and Small Business - Socioeconomic Impacts", *Proceedings, 1993 National Earthquake Conference, Monograph 5*, Chap. 5, pp. 133-60, Memphis, Tennessee: Central United States Earthquake Consortium.

Boisvert, R. 1992. *Indirect Economic Consequences of a Catastrophic Earthquake*, Chapter 7, “Direct and Indirect Economic Losses from Lifeline Damage”, Development Technologies Inc. under FEMA Contract EMW-90-3598.

Brookshire, D., and M. McKee, 1992. *Indirect Economic Consequences of a Catastrophic Earthquake*, Chapter 8, “Indirect Loss Measurement and Computable Equilibrium Model”, Development Technologies Inc. under FEMA Contract EMW-90-3598.

Center for Strategic and International Studies, 1991. *Managing the Economic Consequences of Catastrophic Earthquakes*, Washington, D. C.: Center for Strategic and International Studies (CSIS).

Cochrane, H.; J. Eugene Haas; and R. W. Kates. "Social Science Perspectives on the Coming San Francisco Earthquake--Economic Impact, Prediction, and Reconstruction, Natural Hazard Working Paper #25", Boulder: University of Colorado Institute of Behavioral Sciences, 1974.

Cochrane, H. *A Preliminary Analysis of Damages and Economic Dislocation, in the Loma Prieta Earthquake, Studies of Short-Term Impacts*, Edited by Robert Bolin, Institute of Behavioral Science, University of Colorado, 1990.

Cochrane, H., P. Laub, and J. Barth, 1992. *Indirect Economic Consequences of a Catastrophic Earthquake*, Chapter 4, "Banking and Financial Markets", Development Technologies Inc. under FEMA Contract EMW-90-3598.

Development Technologies, Inc., 1992. *Indirect Economic Consequences of a Catastrophic Earthquake*, Development Technologies Inc. under FEMA Contract EMW-90-3598.

Doherty, N., A. E. Kleffner, and H. Kunreuther, 1991. *The Impact of a Catastrophic Earthquake on Insurance Markets,* Philadelphia, Pennsylvania: University of Pennsylvania, Wharton School, Center for Risk and Decision Process.

Ellson, R. W., J. W. Milliman, and R. B. Roberts, 1984. "Measuring the Regional Economic Effects of Earthquakes and Earthquake Predictions", *Journal of Regional Science* 24 (4):559-79.

Friesma, P.; J. Caporaso; G. Goldstein; R. Lineberry; and R. McClearly. *Aftermath: Communities and Natural Disasters.* Beverly Hills: Sage Publications, 1979.

Gordon, P., and H. Richardson, 1997. "Business Interruption Effects of the Northridge Earthquake," *Growth and Change*, forthcoming.

Gordon, P., and H. W. Richardson, 1992. *Business Interruption Effects of a Major Earthquake in the Newport/Inglewood Fault Zone (NIFZ) - Executive Summary*, Los Angeles, California: University of Southern California, School of Urban and Regional Planning, The Planning Institute.

Howe, C.W. and H. Cochrane. 1992. *A Guide to the Uniform Definition, Identification, and Measurement of Economic and Ecological Damages From Natural Hazard Events.* National Science Foundation, Grant Number CES 8717115, Washington DC.

Kawashima, K., and T. Kanoh, 1990. "Evaluation of Indirect Economic Effects Caused by the 1983 Nihonkai-Chubu, Japan, Earthquake", *Earthquake Spectra* 6 (4):739-56

Kokoski, Mary F., and V. Kerry Smith. "A General Equilibrium Analysis of Partial Equilibrium Welfare Measures: A Case of Climate Change", Unpublished paper, 1984.

Miller, R. and P. Blair, 1985. *Input-Output Analysis: Foundations and Extensions*, Englewood Cliffs, NJ: Prentice-Hall.

Monroe, Tapan, 1989. "The Economic Impact of the Loma Prieta Earthquake of 1989: A Preliminary Look", unpublished paper, Pacific Gas & Electric Company.

Munroe, T., 1990. "The Economic Impacts of the 1989 Loma Prieta Earthquake on the San Francisco Bay Area", *Proceedings of a Forum on the Economic Consequences of a Catastrophic Earthquake*, Washington, D. C.: National Academy Press.

National Research Council, 1992. *The Economic Consequences of a Catastrophic Earthquake*, Washington, D. C.: National Academy Press.

Oosterhaven, J., 1988. "On the Plausibility of the supply-Driven Input-Output Model", *Journal of Regional Science* 28: 203-217.

Rose, A., and T. Allison, 1989. "On the Plausibility of the Supply-Driven Input-Output Model: Empirical Evidence on Joint Stability", *Journal of Regional Science* 29: 451-458.

Rose, A., and J. Benavides, 1997. "Interindustry Models for Analyzing the Economics Impacts of Earthquakes and Recover Policies: Illustrative Examples", in B. Jones (ed.) *Advances in Social Science Analysis of Earthquakes*, Buffalo, NY: National Center for Earthquake Engineering Research.

Rose, A., J. Benavides, S. Chang, P. Szczesniak, and D. Lim, 1997. "The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions", *Journal of Regional Science*, forthcoming.

Rose, A., J. Benavides, S. Chang, P. Szczesniak, and D. Lim, "The Regional Economic Impact of an Earthquake: Direct and Indirect Effects of Electricity Lifeline Disruptions", paper presented at the 42nd North American Meeting of the Regional Science Association Meeting International Cincinnati, November 10, 1995.

Rose, A., and D. Lim, 1997. *The Economic Impact of Electricity Lifeline Disruptions Stemming from the Northridge Earthquake*, Final Report to the National Science Foundation.

Rose, A., and W. Miernyk, 1989. "Input-Output Analysis: The First Fifty Years", *Economic Systems Research* 1: 229-271.

Roberts, R. Blaine; Jerome W. Milliman; and Richard W. Ellson. *Earthquakes and Earthquake Predictions: Simulating Their Economic Effects*, Technical Report prepared for National Science Foundation under Grant PRF 80-19826, 1982.

Salkin, E. Lawrence and Debra A. Lindsey. "Use of Microcomputers to Assess the Economic Impact Of the Earthquake/85 Exercise", FEMA working Paper.

Salkin, E. Lawrence. "Impacts of Emergencies on Regional Economics", FEMA working Paper, 1985.

Shoven, J., and J. Whalley, 1992. *Applying General Equilibrium*, Cambridge University Press.

Wright, James D. et al., *After the Clean-up: Long-Range Effects of Natural Disasters*, Beverly Hills: Sage Publications, 1979.

Yezer, A. M., 1990. "Measuring the Effects of Catastrophic Earthquakes on Different Regions of the Country", *Proceedings of a Forum on the Economic Consequences of a Catastrophic Earthquake*, Washington, D. C.: National Academy Press.

Young, Robert A., and S. Lee Gray, *Regional Models, Welfare Economics and the Evaluation of State Water Plans*, Department of Agricultural and Natural Resource Economics, Colorado State University, 1984.

Appendix 16A

Default Data Analysis
Synthetic Economies

113 state and county IMPLAN tables were analyzed to derive synthetic transactions matrices for the Default Data Analysis model. A frequency histogram of employment (See Tables 16A.2 through 16A.4) revealed that 90 percent of the tables could be classified as Manufacturing/Service, Service/Manufacturing, or Service/Trade. Since nearly two thirds of employment in these tables can be traced to these three sectors, it was decided that this means of classifying economies could be used as a basis for deriving Default Data Analysis interindustry trade flows. Further adjustments were made to reflect the size of the economy. Four size classes were created resulting in the 12 way classification shown below.

Table 16A.1 Classification of Synthetic Economies

Employment		Type		
Upper Bound	**Lower Bound**	**Manufacturing/ Service**	**Service/ Manufacturing**	**Service/ Trade**
unlimited	2 million	SUP1	SUP2	SUP3
2 million	.6 million	LAR1	LAR2	LAR3
.6 million	30,000	MID1	MID2	MID3
30,000	0	LOW1	LOW2	LOW3

The particular states and counties which were utilized to create the 12 synthetic tables are shown in Tables 16A.5 through 16A.6.

Table 16A.2 Manufacturing/Service

Sector	**0**	**10**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**	**AVG**
Manufacturing	0	0	0	9	25	10	4	1	0	0	0	37.5%
Government	0	0	14	35	0	0	0	0	0	0	0	21.5%
FIRE	0	3	44	2	0	0	0	0	0	0	0	13.6%
Trade	0	42	7	0	0	0	0	0	0	0	0	7.5%
Service	0	46	3	0	0	0	0	0	0	0	0	6.3%
Construction	0	46	3	0	0	0	0	0	0	0	0	6.3%
Transportation	0	48	1	0	0	0	0	0	0	0	0	6.1%
Agriculture	0	49	0	0	0	0	0	0	0	0	0	0.6%
Mining	0	49	0	0	0	0	0	0	0	0	0	0.6%

Table 16A.3 Service/Manufacturing

Sector	0	10	20	30	40	50	60	70	80	90	100	AVG
Government	0	0	1	20	11	1	0	0	0	0	0	28.6%
Manufacturing	0	0	12	18	2	0	1	0	0	0	0	23.4%
FIRE	0	2	29	2	0	0	0	0	0	0	0	13.9%
Trade	0	27	6	0	0	0	0	0	0	0	0	8.4%
Transportation	0	25	8	0	0	0	0	0	0	0	0	8.3%
Service	0	28	5	0	0	0	0	0	0	0	0	7.8%
Construction	0	28	5	0	0	0	0	0	0	0	0	7.1%
Mining	0	32	1	0	0	0	0	0	0	0	0	2.2%
Agriculture	0	33	0	0	0	0	0	0	0	0	0	0.4%

Table 16A.4 Service/Trade

Sector	0	10	20	30	40	50	60	70	80	90	100	AVG
Government	0	0	0	2	7	6	0	1	0	0	0	37.4%
Service	0	1	8	7	0	0	0	0	0	0	0	18.2%
Transportation	0	10	6	0	0	0	0	0	0	0	0	9.3%
Manufacturing	0	9	7	0	0	0	0	0	0	0	0	9.2%
Construction	0	13	3	0	0	0	0	0	0	0	0	7.8%
FIRE	0	13	3	0	0	0	0	0	0	0	0	7.4%
Trade	0	14	2	0	0	0	0	0	0	0	0	6.0%
Mining	0	13	2	1	0	0	0	0	0	0	0	4.1%
Agriculture	0	16	0	0	0	0	0	0	0	0	0	0.5%

Table 16A.5 Manufacturing/Service Economy

Super			Large		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
39,000	Ohio	5,831,755	53,033	King, WA	1,112,072
26,000	Michigan	4,714,837	9,000	Connecticut	1,989,824
13,000	Georgia	3,673,183	19,000	Iowa	1,635,164
37,000	North Carolina	3,858,712	5,000	Arkansas	1,194,095
18,000	Indiana	3,064,277	28,000	Mississippi	1,186,175
29,000	Missouri	2,986,395	33,000	New Hampshire	655,638
53,000	Washington	2,777,829	6,059	Orange, CA	1,514,438
27,000	Minnesota	2,642,082	41,000	Oregon	1,621,333
47,000	Tennessee	2,733,161	23,000	Maine	709,529
55,000	Wisconsin	2,796,572			
1,000	Alabama	2,028,495			

Mid			Low		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
8,059	Jefferson, CO	224,465	48,257	Kaufman, TX	19,758
53,061	Snohomish, WA	212,107	6,069	San Benito, CA	16,274
41,067	Washington, OR	179,331	55,029	Door, WI	15,682
55,009	Brown, WI	123,090	55,093	Pierce, WI	13,707
41,005	Clackamas, OR	129,712	55,099	Price, WI	8,637
55,087	Outagamie, WI	89,502	8,087	Morgan, CO	12,408
48,121	Denton, TX	88,726	41,015	Curry, OR	8,996
49,057	Weber, UT	77,041	48,285	Lavaca, TX	9,272
55,089	Ozaukee, WI	36,021	55,129	Washburn, WI	6,590
48,139	Ellis, TX	31,798	41,035	Klamath, OR	28,783
41,071	Yamhill, OR	30,416	55,109	St.Croix, WI	23,213
16,000	Idaho	547,056			
50,000	Vermont	345,166			
44,000	Rhode Island	554,121			
10,000	Delaware	414,343			

Table 16A.6 Service/Manufacturing Economy

Super			Large		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
36,000	New York	9,747,535	19,000	Iowa	1,635,164
6,037	Los Angeles, CA	5,108,213	40,000	Oklahoma	1,614,109
48,000	Texas	8,900,073	4,013	Maricopa, AZ	1,212,392
34,000	New Jersey	4,327,815	22,000	Louisiana	1,969,967
25,000	Massachusetts	3,644,604	5,000	Arkansas	1,194,095
6,000	California	16,532,145	31,000	Nebraska	987,260
13,000	Georgia	3,673,183	54,000	West Virginia	769,662
51,000	Virginia	3,695,334	4,000	Arizona	1,870,344
24,000	Maryland	2,697,448	20,000	Kansas	1,485,215
8,000	Colorado	2,017,818	49,000	Utah	895,454

Mid			Low		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
35,001	Bernalillo, NM	306,176	35,041	Roosevelt, NM	7,593
53,053	Pierce, WA	263,512			
41,051	Multnomah, OR	441,788			
53,063	Spokane, WA	192,662			
48,085	Collin, TX	103,086			
6,089	Shasta, CA	71,398			
48,485	Wichita, TX	74,491			
49,011	Davis, UT	78,170			
6,071	San Bernardino, CA	529,198			
49,035	Salt Lake, UT	436,832			
6,065	Riverside, CA	434,846			
6,111	Ventura, CA	313,911			

Table 16A.7 Service/Trade Economy

Super			Large		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
	NONE		11,000	District of Columbia	761,680
			32,000	Nevada	741,574
			15,000	Hawaii	696,759
			35,000	New Mexico	745,539

Mid			Low		
FIPS	**STATE/CNTY.**	**EMPLOY.**	**FIPS**	**STATE/CNTY.**	**EMPLOY.**
30,000	Montana	433,623	48,397	Rockwall, TX	9,140
8,005	Arapahoe, CO	217,208	8,067	La Plata, CO	19,079
4,003	Cochise, AZ	39,611	56,001	Albany, WY	16,959
38,000	North Dakota	377,987	56,041	Uinta, WY	9,948
6,029	Kern, CA	262,422	55,125	Vilas, WI	8,364
56,021	Laramie, WY	44,438	35,061	Valencia, NM	11,787